The Northern Pocket Gopher–

Most of What You Thought You Might Want to Know, but Hesitated to Look Up

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Most of What You Thought You Might Want to Know, but Hesitated to Look Up

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Dedication

I dedicate this paper to:

all Forest Service employees who confront pocket gopher problems,
all employees who confront other Forest Service employees,
all Forest Service employees who have problems,
all problem employees,
all employees who know enough about gophers,
all employees who don't know enough about gophers,
all employees who want to know more about gophers,
all employees who don't care to know more about gophers,
all employees who "go pher" other employees,
all employees who listen to stories about gophers,
all employees who listen,
all employees who don't listen,
all employees who write EAs and BEs for gopher control,
all employees who don't care about EAs or BEs for gopher control,
all employees who don't know what an EA or BE is,
all employees who write for a living,
all employees who work for a living,
all employees who work in the forest,
all employees who provide a service to other employees,
and finally,
all employees employed by the Forest Service.

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Purpose

This guide is intended to consolidate information on controlling pocket gophers, to simplify the Districts' task of preparing an Environmental Analysis (EA) for pocket gopher control on the Wallowa-Whitman National Forest, and to reduce the bulk of material in the Environmental Analysis. Site-specific data are still required for individual units prescribed for pocket gopher control.

According to the ***"Regulations For Implementing The Procedural Provisions Of The National Environmental Policy Act,"*** 40 CFR 1502.21, Environmental Analysis writers can incorporate this entire document as part of their EA by including a statement such as the following:

The document ***"The Northern Pocket Gopher - Most of What You Thought You Might Want to Know but Hesitated to Look Up,"*** by Ronald E. Bonar (1995) is hereby incorporated by reference as per 40 CFR 1502.21. It includes a description of the biology, behavior, and effects of pocket gophers; damage control authorities and alternatives; approved rodenticides, secondary and nontarget poisoning possibilities.

Introduction

Pocket gophers ***(Thomomys sp.)*** constitute *"the single most destructive group of species on National Forest System (NFS) lands"* (Borrecco and Black 1990), and the most serious animal hazard to recently reforested areas in the western United States. They threaten the reforestation success in pine regions throughout the Pacific Northwest. The northern pocket gopher ***(T. talpoides)*** *"has the widest distribution of all pocket gophers, extending from Central Alberta to northern New Mexico and Arizona, and from the western three-fourths of North Dakota and South Dakota to eastern Washington, Oregon and northeastern California"* (Chase et al. 1982), and also constitutes the most serious animal damage problem on the Wallowa-Whitman National Forest. Pocket gopher damage has been reported for almost every commercial coniferous species in the West, and if gophers and regenerating conifers occur in the same place, similar levels of damage can occur.

Range of the Northern Pocket Gopher ***(Thomomys talpoides)*** in North America.

"Regardless of cause, gopher feeding on trees at damaging and often catastrophic levels is widespread" (Crouch 1979). Pocket gophers, which neither state nor federal law protect, have a serious economic impact on coniferous plantations, because the damage caused by their feeding and burrowing seriously retards and nullifies reforestation efforts. Gopher damage limits the reforestation of pine, fir, and other conifers on over 296,000 acres in the western United States and results in the loss of millions of dollars worth of potential timber (Anthony and Barnes 1978).

Although farmers recognized gopher damage to agricultural crops since the early 1900's, damage to planted trees has been reported only since the 1940's. Pocket gophers have been feeding upon conifers for thousands of years, but their economic importance intensified in the 1950's when foresters began practicing even-aged management over extensive areas. Clearcut harvested areas, sites prepared by hand, machine, or prescribed fire, provide ideal habitat for the growth of gopher-preferred foods, and consequently, the increase and spread of pocket gophers. Therefore, conifers planted on these harvested units provide supplementary gopher food from late fall to early spring.

In this literature review of the scientific information available, I have displayed many of the known facts about pocket gophers and suggested alternative solutions to control gopher damage. I have also presented data about pocket gopher species and genera other than ***T. talpoides*** to give a more comprehensive picture of pocket gophers in general. However, not all authors cited in the references specified the exact species or genera for their statements, so I often interjected the proper species or genera where I could determine it. Although I primarily concerned myself with pocket gopher damage to reforested areas, I also covered its effects on range vegetation, wildlife, and soils. The final decision to utilize this information remains with the line officer who signs site specific Environmental Analyses (EA).

All forest ecosystems are dynamic, and various animals occupy various niches at various times within those ecosystems. Because forest trees contribute a portion of the natural diet of many species of consumptive and nonconsumptive wildlife, "animal damage" becomes an issue when certain species or combinations of species utilize to an excessive degree an environment that land managers want less heavily utilized by those species. In other words, land management practices change the carrying capacities of different habitats by affecting cover and the amount, diversity, and nutritional quality of available forage. To keep a species' use of forest resources within acceptable levels, land managers must have a basic understanding of those species' physiological requirements, their normal behavioral reactions, and their probable responses to habitat changes. Wight (1918) put it quite simply three-fourths of a century ago, *"It is not possible to determine the best method of control of any pest without becoming acquainted with the habits of that animal, therefore, the study of the pocket gopher from the standpoint of its natural history is not only correlated with, but actually a part of, the seemingly more practical work on the methods of its control."*

"Animal damage control is a fundamental part of wildlife management. It is not a separate entity; never an end in itself. The control of animals is never the objective; rather the prevention of various kinds of damage necessary to accomplish a specific management objective" (Berryman 1989). Notwithstanding, wildlife biologists and foresters frequently question the effectiveness of pocket gopher control. We argue that treating the symptom, i.e., an excessive population, rather than the cause, i.e., optimum habitat conditions for a population increase, does not solve the problem efficiently. In addition, we question the primary and secondary effects of the most commonly used rodenticide–strychnine, a word that, metaphorically speaking, sends shivers down the spines of many natural resource professionals.

Animal damage control *"works in harmony with research, enforcement, protection, and acquisition as one means of regulating animal numbers to accomplish a specific management objective. It is also necessary to this Nation's production of food and fiber and as a service to constituents in protecting communications and transportation and human and animal health. In short, it is a vital function and its practitioners are integral contributors to rational resource management–in no sense second class citizens in the resource community"* (Berryman 1989).

Because animals do not always respond to particular habitat changes in the same way, population control planning and attempted management of animal populations must center on site-specific factors analyzed in a National Environmental Policy Act (NEPA) document. Although pocket gopher control seems to point to one standard treatment in almost every case, the NEPA process allows land managers the option to consider other treatment alternatives to meet the site-specific problems that present themselves annually.

In this paper, I define damage to trees as the use of tree parts for food by pocket gophers that results in slowed growth or death of the tree; delayed regeneration of the plantation; reduction of stocking in the plantation; and lengthened rotation.

Because pocket gophers have the ability to modify their habitat, some land managers may consider those modifications "damage." For example, the pocket gophers' use of forage plants for food and the resultant modifications in the range environment caused by burrowing and mounding generate changes in plant species' numbers, composition, and density, all of which affect the use of that environment by domestic livestock and wildlife. Also, burrowing and mounding change the existing soil structure by depositing and mixing subsoil on the surface, which affects some soil chemical changes, and exposes this surface soil to movement by wind, water, and gravity.

Gopher activity becomes less evident in densely forested areas, and more common in meadows, riparian areas, road cuts and fills, and other openings in the forest canopy. Pocket gophers quickly colonize any newly created habitat adjacent to already occupied areas if land management practices or natural catastrophes, such as windstorms, fires, or insect attacks generate new open-canopied areas that respond by producing seral vegetation.

The common name "pocket gopher" refers to the deep fur-lined external cheek pouches (pockets), located wholly outside the mouth, and used to carry food and nesting materials–never soil. These pockets are eversible, i.e., they can be turned inside out (Marsh and Howard 1978). Pocket gophers do this regularly as part of their grooming behavior (Wight 1918).

The genus name ***Thomomys*** is derived from the Greek word "thomos" meaning "heap," (a reference to the mounds), and "mys," the Greek word meaning "mouse."

Left foreclaws of ***Geomys bursarius*** and ***Thomomys talpoides*** (shown at twice size).

Physical Parameters

Description

"*Pocket gophers are mobile weeds,*" (Kuhn 1983) or as others might say, mobile weed eaters. These stout-bodied, short-legged rodents have blunt heads and exhibit little external evidence of a neck. Their prominent yellow, sharp, chisel-like incisors are curved, smooth-faced, and protrude from the mouth. Furred muscular lips close firmly behind the incisors to prevent soil from entering their mouth while foraging or digging burrows. Their incisors have no roots, but grow from a persistent pulp as long as the gopher lives. The upper ones grow about 9 inches (23 centimeters) a year, and the lower ones up to 18 inches (46 centimeters) per year (Chase et al. 1982). Burrowing, foraging, and grating their teeth are important activities that help gophers wear down these continuously-growing incisors. More growth occurs on the lower ones because gophers utilize their lower jaw more than the upper jaw. Therefore, the more rapid abrading and chipping of these lower teeth cause faster wear, and subsequently faster regrowth.

Gophers have small ears and a well-developed sense of smell. *"The auditory ability of **T. talpoides** is comparatively less than that of most rodents"* (Chase et al. 1982). Even though the gophers' small, widely-set eyes sit high on their forehead, they have a very limited range of vision. However, their *"eyelids are so close fitting that even fine sand cannot penetrate them"* (Chase et al. 1982).

Gopher bodies are morphologically well suited to underground living and a fossorial (adapted for or used in burrowing) existence. They have small, somewhat flattened heads, and thick, muscular shoulders. Their well-muscled, powerful forearms have long curved claws on the forefeet that are well adapted for burrowing. Gophers dig mostly with their front feet, and the middle three claws on their forefeet grow about 5-1/2 inches (14 centimeters) per year, or about twice what the other nails grow (Chase et al. 1982). Constant burrowing keeps these claws to a manageable size.

"Northern pocket gophers vary in size throughout their geographic range. Body size varies with vegetative type, locality, altitude, and latitude...Adult males are about 10 percent heavier and three to four percent longer in total length than adult females" (Turner et al. 1973). They also suggested that depth of soil, along with porosity and friability *"encourage natural selection for certain morphological characteristics,"* which Dalquest and Scheffer (1944) stated 29 years earlier. *"Definite correlations [exist] between body size and depth of soil."*

Adult ***T. talpoides*** range from 6-1/2 to 10 inches (17-25 centimeters) long (Case 1983), excluding a 3- to 4-inch (8- to 10-centimeter) lightly-haired tail. (I have not yet spoken to anyone who works in northeast Oregon who claims to have seen a northern pocket gopher longer than the above-stated ***lower*** limit.) Vibrissae (whiskers) around the nose and mouth, and the scattered guard hairs on the rump and tail are very sensitive to touch, and function as sensory units as the gophers move backward or forward through their tunnels (Chase et al. 1982). Sensitive to heat, the tail and feet probably act as thermoregulatory organs (Turner et al. 1973). Chase et al. (1982) states that increased blood circulation in a pocket gopher's tail dissipates heat, and since the ratio of body size to tail length varies by local climatic conditions, this helps explain their ecological distribution. For example, northern pocket gophers at higher altitudes generally have larger bodies and shorter tails than their counterparts at lower elevations.

Pocket gophers have fine textured, soft, glossy hair, not really fur (Crouch 1933). The nap of its coat lays toward the tail and close to the body, and is *"so soft and silky that it is not readily soiled by contact with damp earth"* (Scheffer 1910). Gophers molt at irregular intervals. The hair color of ***T. talpoides*** varies, but generally runs from brownish to gray/black with a paler underbelly. The throat and feet may have white patches. Because of their low dispersal rate and subsequently limited gene flow, gopher populations adapt well to local conditions, and therefore, exhibit little color variation within a local population (Case 1983). Thus, local soil color may play a role in hair color, with darker pelage in darker soils and lighter pelage in lighter soils (Teipner et al. 1983).

Northern pocket gopher.

"Because of the nature of their habitat, pocket gophers have not evolved behavioral displays or vocalizations to use as self-advertisements to defend their territories" (Turner et al. 1973). Whether they do or do not vocalize in the wild, they do make aspirated sounds, squeals, murmurs and chatter their teeth when trapped, bitten, or annoyed (Chase et al. 1982). Wight (1918) states, *"When caught in a trap and suffering severely, as is often the case, they* **[T. bulbivorus]** *make a cry of pain. This is also true when they are fighting and the teeth pierce the skin; otherwise the sounds are all gentle and subdued. The female and male both make calls peculiar to each when together, which may be described as half way between a crooning sound and a purr. The mother gopher seems to have a method of talking to the little ones and they twitter away, sometimes sounding like a nest of birds."* ***T. talpoides*** click their teeth and make a squeaky sound when suspended by their tail (personal observation). In reality however, the solitary existence of pocket gophers does not require a very complex system of vocal communication.

"Researchers have not developed reliable techniques for aging animals [pocket gophers] beyond 1 year" (Teipner et al. 1983), the age that approximates maturity. Immature pocket gophers from about 6 months of age until maturity express little external urogenital differences between the sexes (Chase et al. 1982). When sexing live-trapped subadults, applying pressure inward to the scrotal area causes the penis to extrude on males. The female's pubic gap generally forms between 9 and 12 months of age.

Reproductive males grow as big or bigger than females, and bigger than nonreproductive males, but nonreproductive females achieve about the same size as reproductive females (Reichman et al. 1982). Male pocket gophers continue growing throughout their lifetime, whereas females grow very little after reaching sexual maturity (Chase et al. 1982). Males generally weigh more than females, but weights fluctuate widely, depending on the season. Adults range from 90 to 170 grams (3 to 6 ounces) (Matschke et al. 1990). However, Matschke et al. (1992) find that ***Thomomys talpoides*** in northeast Oregon ranged from 44 to 90 grams (1.5 to 3 ounces).

Territorial Behavior

A single gopher generally occupies its own burrow system, except that adjacent systems may have a common tunnel, which gophers usually plug with soil, which separates the two individuals. Although *"there are no significant relationships between [body] masses of the animals* **[T. bottae mutabalis]** *and the sizes of their home ranges"* (Reichman et al. 1982), the home ranges of males do not overlap with those of other males. The same generally holds true for females. However, a male's home range may overlap one to several female home ranges. Living as solitary individuals, except during the breeding season and when females rear their young, adults and subadults of both sexes generally are thought to remain highly territorial and extremely intolerant of each other.

The lack of sufficiently detailed observations on the characteristics of territorial behavior in pocket gophers in nature has led many authors to think that gophers vigorously defended their territories through combat. Though gophers fight ferociously, they generally flee from their opponents whenever they have the opportunity. When artificially confined, however, gophers usually begin with an outward display of grinding teeth and chattering, then fight until only one remains alive. Nonetheless, pocket gophers appear docile to humans, rarely biting, even when suspended by their tails (Chase et al. 1982 and personal observation).

Pocket gopher males were thought to be polygamous, i.e., one male serving two or more females. However, Reichman et al. (1982) reveal that with ***T. bottae mutabalis,*** serial monogamy more likely prevails, i.e., males and females may visit each other's burrow system during the breeding season, and some females may share a common nest with more than one male, each one probably visiting her at different times through interconnecting tunnels.

Plural occupancy of burrows was thought rare, but Moore and Reid (1951) found that half-grown Dalles pocket gophers ***T. talpoides quadratus*** began tunneling off the parent burrow system, which may allow a combination of adult males, adult females and juveniles all using part of the same burrow system. Some biologists speculate–and others dispute–that the male may even help care for the young. Kuck (1969) believes that during the dispersal of the young, resident northern pocket gophers may spend part of their time defending their burrow system from aggressive juveniles. Turner et al. (1973) sums it up nicely. The *"northern pocket gophers' system of defending individual territories is considerably relaxed during the breeding season. Almost every combination of adult males, adult females, and young can be found in the same burrow system during the spring and summer...There appears to be a high degree of tolerance throughout the breeding season and the period of caring for young."*

Scheffer (1910) mentions trapping two ***Geomys bursarius*** *"on several occasions"* in the same tunnel (not during the mating season). Washburn and Mickel (1925) reports two cases of a second occupancy of a ***G. bursarius*** burrow 2 days after the death of the first occupant, and Tunberg et al. (1984) documents a case where three different ***T. bottae*** occupied one burrow system during a 40-day period. Chase et al. (1982) also cites examples of possible plural occupancy and the possibility that some tunnels *"were more or less common property."* They also cite the results of homing experiments with ***T. bottae,*** in which individual gophers reached their burrow systems after traveling up to 650 feet (200 meters) underground without being caught in drift fence traps on the surface. These examples indicate the possibility of a nonsolitary existence or a very rapid reinvasion of burrow systems.

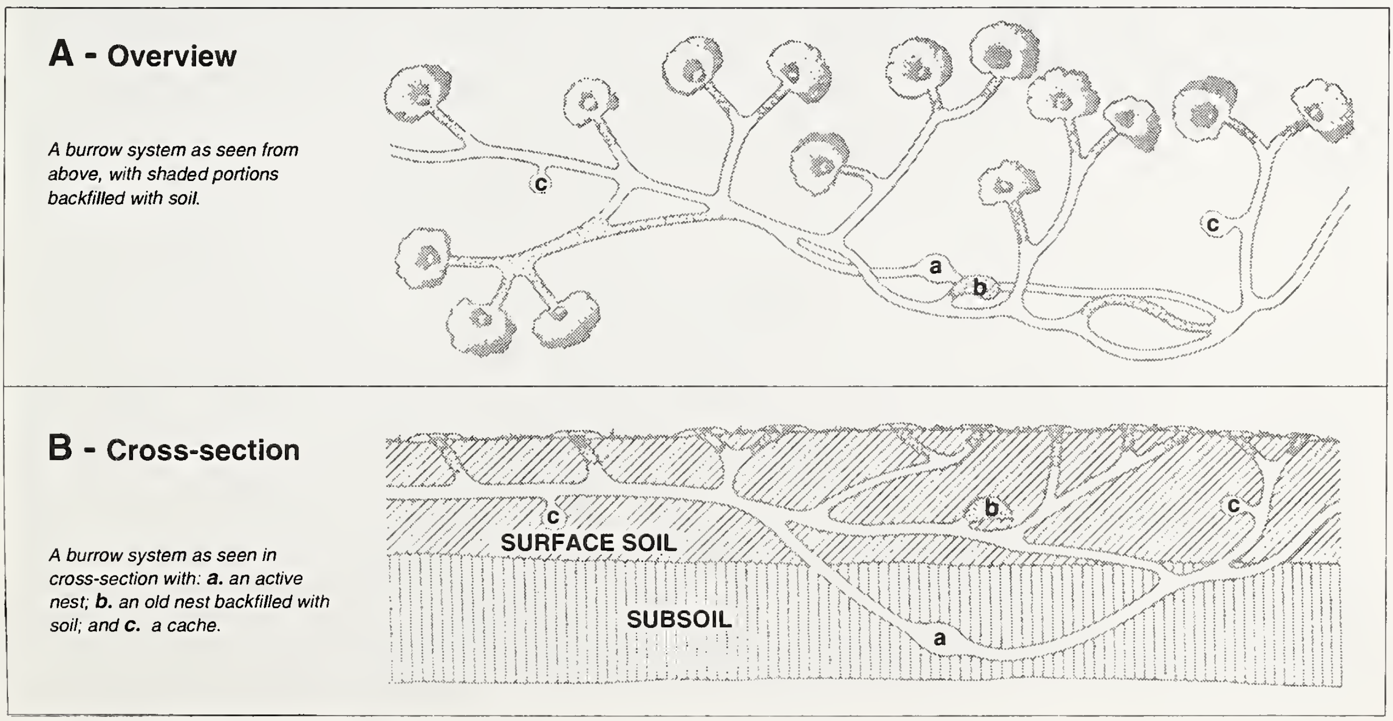
Reichman et al. (1982) find that ***T. bottae*** sometimes reoccupy vacated burrows within minutes or hours, and suggest that gophers become aware of each other's presence, and possibly even each other's location. Since pocket gophers appear sensitive to underground vibrations, some researchers (Turner et al. 1973) think that gophers detect each other's nearby presence. As they dig burrows toward each other, one or both of them respond to an *"alarm reaction."* That is, if one gopher burrows within about 10 centimeters of a neighbor's burrow, it retreats and throws soil toward the other burrow as if it were attempting to create a wall between its territory and that of the other pocket gopher.

Burrow System Configuration

"Each burrow system is essentially an exclusive area that varies with the size of the individual, soil type and plant production...The placement and geometry of individual burrows play an important role with regard to interactions between neighbors and internal management of resources of which each pocket gopher has exclusive use" (Reichman et al. 1982). The home range of a pocket gopher generally consists of its own burrow system. Males generally have larger systems than females. At low population densities, gophers create larger and irregularly clustered burrow systems with ample space between individual territories. But at high population densities, the gophers have smaller and more regularly distributed territories. Areas of abundant food support higher gopher densities and smaller burrow systems. Besides shelter, burrow systems provide access to forage and mates, and a means to avoid neighboring gophers.

Reproductive males usually have more linearly-shaped burrow systems (Case 1983), a greater burrow length and a greater burrow system perimeter. Therefore, they have more adjacent neighbors than females or nonreproductive males (Reichman et al. 1982). Spacing within and between individual burrow systems varies little for all sizes and both sexes, i.e., for both reproductive and nonreproductive male and female ***T. bottae.*** But if plant production in an area decreases, the gophers tend to increase the length of their burrow system rather than alter the spacing between burrow systems (Reichman et al. 1982).

Chase et al. (1982) find the home range of an adult male northern pocket gopher averaged about 0.06 acres (about 242 square meters), and for an adult female, about 0.03 acres (about 121 square meters). But Kuck (1969) finds that adult northern pocket gopher males averaged 0.03 acres (121 square meters), adult females 0.02 acres (81 square meters) and juveniles 0.02 acres (81 square meters). The literature on pocket gophers claims a low of one gopher ***(G. bursarius*** or ***Cratogeomys castanops)*** per acre (Altman 1979) to an *"excess of 200 gophers [****T. bottae****] per acre"* (Tickes 1983), i.e., about one gopher every 218 square feet, or one about every 4.5 meters (see ***Population Dynamics,*** page 11.)



A simulated pocket gopher burrow system.

The main "building block" of a burrow system consists of a "node-internode," that is, an extension of a burrow segment by adding a fork and a lateral. The lateral segment terminates in the characteristically fan-shaped mound. Gophers can also push soil from new burrows into unused burrows, or force their way through very loose soils to create new burrows without pushing up new mounds (Moore and Reid 1951). Gophers dig burrow systems consisting of subsurface and deep main tunnels that run approximately parallel to the ground surface–with many lateral branches–in an overall narrow, elongated shape.

Pocket gophers probably construct more tunnels in their lifetime than any other North American rodent. Each burrow is just slightly larger in diameter than their body width. So, depending on the size of the inhabitant, northern pocket gopher tunnels will average about 3 inches (8 centimeters) in diameter, range from about 80 to about 800 feet (24 to 240 meters) in total length (Teipner et al. 1983), and descend about 6 feet (1.8 meters) (Crouch 1933 and Tunberg et al. 1984), depending on soil depth, moisture, and ambient temperature.

Tunnels access nests, food caches, dumps, and sumps. Each burrow system has one or more nest cavities that resemble circular chambers 4 to 8 inches (10 to 20 centimeters) in diameter, depending on the size of the resident. Gophers access them from two or three interconnecting tunnels dug deeper than feeding burrows, and line them with shredded grass and other vegetation for bedding. They also make nesting cavities in the snowpack by constructing a hollow ball of shredded plant material. Kuck (1969) finds that juvenile northern pocket gophers shifted their den (nest) locations during the summer, but adults seldom did so. He concludes that incorporating all the periods of inactivity, a gopher spends 50 percent of its time in only 4 percent of its home range, i.e., in or near its nest.

Gophers also construct other circular cavities known as caches and dumps. They use caches to store food materials such as pieces of roots, leaves, and grains brought in from the feeding burrows. Many researchers think that gophers cache more food than they eventually consume. Others (Turner et al. 1973)

Fresh gopher mounding.

speculate that caches, which tend to contain mostly roots, lead people to believe that gophers consume more roots than studies of stomach analyses demonstrate. They also report finding *"apparently unused"* caches that still held large amounts of stored food.

Sometimes gophers use old nests and tunnels as dumps to deposit urine, feces, unused food items, and other debris, including dead individuals of the same species (Tunberg et al. 1984). They seal them off from the main tunnel system by backfilling them with excess soil. Wang et al. (1986) find that pocket gophers sometimes leave feces in nests or food caches. Dumps, with their concentration of feces, also accumulate the spores of hypogeous (below ground fruiting bodies) mycorrhiza-forming fungi. These survive the pocket gopher's digestive tract after the animals eat the underground mushrooms, and increase the probability of colonizing rootlets of conifer seedlings within the burrow system (Maser, Trappe and Nussbaum 1978).

Near the bottom of many burrow systems, gophers dig short steeply-pitched, dead-ended tunnels. These function as sumps or drains to eliminate water from the main tunnel system (Stewart and Baumgartner 1973).

Case (1983) estimates that pocket gophers [no species mentioned] create one to three mounds per day, up to 70 per month, or up to 200 mounds per year, beginning after snowmelt, abating during the summer, and increasing again in the fal l. Green et al. (1987) find that minimally disturbed broadcast burned sites had 300 mounds per acre (740 per hectare), whereas heavily disturbed, dozer-piled sites had 6,000 mounds per acre (14,800 per hectare) in their north Idaho study area [probably ***T. talpoides***]. In their study of ***T. bottae*** in northern Arizona mountain meadows, Castor and Whitham (1989) find gopher disturbance ranged from a relatively low of 0.7 mounds per meter^2, that is, 2,888 mounds per acre, to a high of 5.5 mounds per meter^2, that is, 23,100 mounds per acre.

Gopher nest.

Burrow systems are dynamic. Their placement and pattern reflect how gophers interact with their neighbors and how they use the available food resources. Since *"burrow length correlates with habitat productivity"* (Steuter et al. 1990), the poorer the habitat, the more burrow length the gophers need to forage, and the more mounds they build.

Gophers create horseshoe or fan-shaped mounds because they push soil up through a hole–about the size of a silver dollar–at the edge of the mound. Moles also create mounds, but theirs resemble miniature volcanos, because moles also push soil up through a hole–about the same size as a gopher hole–in the center of the mound. Gophers generally push up mounds in an irregular pattern, whereas moles tend to push up a series of mounds in relatively straight lines. Voles (meadow mice), create smaller tunnel openings–about the size of a half dollar–do not mound soil at their tunnel entrances, and connect their holes with visible aboveground trails.

Wight (1918) attributed to ***T. bulbivorous*** another type of mound which he called the "chimney-shaped mound." He says that gophers build them in the spring with a centralized hole that leads *"a comparatively long distance straight back into the main runway,"* and speculates that they keep them open to help dry out the burrow system and/or *"to protect the gopher from any enemy of its own kind."*

Besides mounds, gophers construct one other type of above ground sign during snow-free periods. Off main runways, gophers dig short, almost vertical tunnels to the surface. They use these to access surface vegetation. After using them, they fill these holes with earth plugs or "dollar-sized plugs," which they construct by placing a small amount of soil at the perimeter of the hole and packing it firmly with their chin and paws. They continue this process until they close the entire hole. Gophers construct these plugs level with the ground, and may also use them to cover any small break in the tunnel system exposed to the surface. Some plugs tend to lose their form after 48 hours, but others last much longer (Anthony and Barnes 1978).

Fresh gopher activity after a long rain.

Behavior within the Burrow System

Being fossorial, gophers live an almost entirely subterranean life, caring *"neither for the enticing warmth of sunshine nor the witchery of moonlight"* (Scheffer 1910). Not counting their activity under the snowpack, they surface to push soil from their burrow, to feed on succulent plants near a burrow entrance, to seek new territory when driven from their burrow by a predator, or as a juvenile, when ejected from the maternal burrow. Ever vigilant while exposed, they reenter their burrow at the slightest hint of danger and fill the hole with a soil plug (Wang et al. 1987). Gophers closely regulate the environment within their burrows and will usually plug any opening in their system within 24 to 48 hours if the humidity at ground level remains less than 94 percent (Hungerford 1976). However, Campbell et al. (1992) find that some of their radio-equipped gophers did not plug their holes within 48 hours, and *"in other plots pocket gophers with radio transmitters were found dead, but their opened burrows were plugged by other gophers."*

"The gopher follows his own sweet will in mining,...heading everywhere in general and nowhere in particular" (Scheffer 1910). It appears from anecdotal evidence that northern pocket gophers seem most active and excavate more soil from dusk through dawn, and build more mounds during the evenings and mornings. Anderson and MacMahon (1981) have detected activity–but not necessarily burrowing–about half of the day, and periods of rest about half of the day for ***T. talpoides.*** Other researchers state that gophers excavate new burrows and plug old ones during the day or night, and remain generally active with intermittent rest periods, throughout the entire day. External light or darkness seems to have little effect on their cycle.

Kuck (1969) also finds that northern pocket gophers remain active throughout the day, but 75 percent of their activity takes place during the daylight hours, with 46 percent of all activity taking place between 10 a.m. and 4 p.m., 21 percent between 4 and I0 p.m., 10 percent between 10 p.m. and 4 a.m., and 23 percent between 4 and I0 a.m. He finds that the periods of inactivity last longer than their bursts of activity; juveniles stay active for longer periods than adults; adult females have more activity than adult males; and concludes, that *"digging may not be a reliable index to gopher daily activity."*

Therefore, the amount of surface sign, does not provide a consistently reliable all-season indicator of their movements. Gopher activity varies among individuals based on the availability of food and by their level of security (Hungerford 1976). If gophers have sufficient food cached, daily consumption can vary from one-third to one-half of its own weight (Wight 1918). Or, if external forces do not disturb them, they scurry around through their burrow system, but make little to no aboveground disturbance until they need to secure food, avoid predation, or replace destroyed tunnels.

Kuck (1969) finds that the radioisotope-tagged northern pocket gophers in his study apparently felt the vibrations he made on the ground, because *"whenever I located a gopher away from its den, it would immediately return to the den. If located at the den site, the gopher would not move while I was present."* This contrasts with one of my personal experiences. While inspecting the planting of a harvested unit in northeast Oregon, I noticed a seedling planted no more than 1 minute earlier, slowly sinking underground. I walked up to it and pulled it up to normal planting height and stepped back about 8 feet (2.4 meters). The seedling began descending into the ground again. I pulled it up and backed off three times before I decided to let the gopher have it. Despite the fact that three adult males walked within a 10-foot (3-meter) radius of that seedling, the pocket gopher apparently remained quite close so it could begin pulling the seedling into the burrow seconds after I moved.

Pocket gophers remain active throughout the year, but seasonal activity generally varies according to soil moisture levels. Kuck (1969) finds little correlation between activity and soil moisture levels in the spring. Then *"as available moisture decreased during July and August, the activity of gophers correspondingly decreased,"* and continued until the late summer/fall rains. He attributes the lull in activity in early June to *"behavior changes during the breeding season,"* when several females in his study cared for their young. This period was followed by a sharp increase in activity during late June and July, probably due to an increase in demand for food by the adults and young, and/or by the increased availability of forbs. In general, he finds that despite their smaller home ranges, adult females and juveniles scurried around more and moved farther from their den more often than did adult males.

During hot, dry summers, gophers appear to spend less time near the surface, and more time at deeper depths where higher humidities persist and fluctuate less. Kuck (1969) speculates that some of the radioisotope-tagged northern pocket gophers in his north Idaho study area may have aestivated, i.e., spent the hottest part of the summer in a state of dormancy. He bases this assumption on his observations that the gophers that used deep dens or shallow dens in the early summer, continued to use the same ones during the late summer, and did not dig other deeper ones. Several gophers remained *"inactive for long periods of time,"* including one adult male that remained inactive *"from August 8 to 21."*

Pocket gophers keep their runways relatively tidy by pushing fecal pellets, unused food material, other debris or soil from new burrow building or regular burrow maintenance into dumps and unused tunnels. With few exceptions gophers only push loosened soil and small rocks to the surface. Campbell et al.(1992) cites the recovery on the surface of a radio transmitter they had placed in a diphacinone-treated bait block. Contrasted to older mounds, fresh mounds usually appear darker in color because soil moisture has not yet evaporated.

Mounding depends on belowground burrowing conditions, food availability, and unknown stochastic (random) variables. In northeast Oregon, gophers appear more active in the late summer and fall probably because recently dispersed juveniles are actively burrowing and establishing their own territories; gophers create more feeding burrows and mounds while searching for the preferred and less available succulent foods and caching roots to sustain themselves during the winter. Gopher activity during and immediately after heavy rains generally lessens, possibly because their body hair, normally soft and glossy, and their claws accumulate too much mud.

Gates and Tanner (1988) state that no apparent relationship exists between plant nutritional levels and mounding activity. However, in poor habitats, the energy requirements for burrowing, breeding and gestation can often exceed the productive capacity of the site. In the early seral stages of plant communities, even though gophers can consume up to 30 percent of the primary productivity of the belowground parts of meadowland forbs, random events associated with weather and ease of burrowing may limit population growth.

"Plant composition and abundance are probably the primary regulators of gopher density" (Teipner et al. 1983). In areas with limited food supplies, gophers dig more feeding tunnels and create more mounds in the process in an attempt to locate more food. This gives the appearance of a heavier population than actually exists. Gates and Tanner (1988) speculate that gophers *"select home ranges within each site that allows them to meet their nutritional needs."* However, Case (1989) suggests that researchers have not yet determined the reasons why pocket gophers dig, and proposes, though disputed by other researchers, that the size of the animal and bulk density of the soil have more relevance than aboveground and belowground resource availability (see pages 12-18).

Soil depth and texture do affect gopher burrowing activity. Because a 3-inch (8-centimeter) diameter burrow cannot support itself in soil only 4 inches (10 centimeters) deep, burrows dug in such shallow soil generally cave in. Although pocket gophers do construct shallow burrows, those near the surface maintain too much heat and not enough moisture during the summer. They also remain too cold in the winter, especially when freezing temperatures precede an insulating snow cover. As a consequence, the combination of regional climate and soil depth tends to influence the local distribution of pocket gophers. For, if the soil has sufficient depth, porosity, and friability, gophers may dig deeper tunnels to avoid extremes of heat and cold.

Burrow air temperatures approximately equal the soil temperatures at corresponding depths (Turner et al. 1973). Pocket gophers can maintain their body temperature of 98°F (37° C) in an ambient temperature range of 35° to 85°F (2° to 30°C). However, above 85°F (30°C), their ability to dissipate heat decreases and their body temperature rises. Exposure of 1 hour to 100°F (38°C) can cause death (Chase et al. 1982). They also cite a study of northern pocket gophers in Colorado where measured burrow temperatures ranged from 50° to 64°F (10° to 18°C) in the summer, and 30° to 35°F (-1° to 2°C) in the winter.

Northern pocket gophers can burrow 1.5 to 2.0 centimeters per minute (about 3 to 4 feet per hour) depending on the type of soil, its moisture content, and temperature (Andersen and MacMahon 1981). They also state that *"stochastic events associated with weather affect energy acquisition (burrowing) rates, and thus survivorship."* In other words, weather directly relates to how much food a gopher can secure per time period used for burrowing.

Gophers have more difficulty burrowing through saturated soil, and sometimes have to gnaw through hard or frozen soil. A pocket gopher *"may use its upper incisors to anchor its body in position while digging. Where soils are too hard or stony for the claws to be completely effective, the pocket gopher will often use its incisors to loosen the soil and rocks"* (Chase et al. 1982).

During burrow construction, repair, or maintenance, pocket gophers dig with the claws on their front feet. They push the soil particles, rock, and other loosened debris behind them with their hind feet. When sufficient material accumulates, they make sort of a somersault in the burrow. Then, using their forefeet, shoulders and chest, they push (bulldozer fashion) the material into an unused tunnel or through a lateral and out of the tunnel, where they create the typical horseshoe-shaped mound. They do not carry soil in their pouches (Marsh and Howard 1978).

The per unit energy cost for burrowing ranges from 360 to 3,400 times greater than the per unit energy cost to move around on the surface of the ground (Huntly and Inuoye 1988). Such strenuous fossorial behavior requires a very high metabolic intake in the form of a large food source to supply this continuous demand for energy. Andersen and MacMahon (1981) find that despite these calorically expensive activities, ***T. talpoides*** can secure their energy requirements in a meadow habitat with less than 2 hours of burrowing per day, i.e., about 4 feet (1.2 meters) of burrow length.

Turner et al. (1973) calculate that at an average daily consumption of 80 grams (2.8 ounces) (fresh weight) of food items per day, 22 northern pocket gophers per acre would consume 4 pounds of fresh vegetation per acre (4.5 kilograms per hectare) per day. This converts *"to 1,460 pounds [4 pounds x 365 days] fresh weight, or 365 pounds dry weight, per acre per year, not including vegetation stored uneaten in food caches or used to make nests"* (see pages 18-19).

Since not all gophers have access to fresh vegetation 12 months a year, the above figures only estimate the food requirements. Pocket gophers eat edible roots that they encounter while constructing burrows. They have avaricious tendencies and often pull their food, and sometimes nonfood items like wood, plastic, or wire, into their burrow. They do a very thorough job in recovering any available food, and if necessary, bite larger food items and pull them backwards through their tunnel system. ***T. bottae*** can pull or carry food material two or three times their weight (Wang et al. 1986).

Case (1983) reports that pocket gophers only feed about one body length from their tunnel opening, and immediately re-enter it when disturbed. Marsh and Steele (1992) report that ***Thomomys spp.*** rarely travel more than 18 inches (46 centimeters) from their burrow entrance.

When burrowing through snow, gophers often backfill their tunnels with excavated soil. Turner et al. (1973) report soil packed into snow tunnels as high as 18 inches (46 centimeters) above ground level. After the snow melts, large worm-like casts settle on the ground, serving as evidence of the wintertime presence of pocket gophers. However, the number of casts do not serve as a reliable population indicator (see page 24).

All animals capable of fitting into gopher tunnels, such as mice or snakes can invade and take over a burrow. Ground squirrels and skunks can enlarge the system for their own benefit. Gophers can scare off some vertebrate intruders, or as a last resort, throw up a wall of soil to block off the invaded tunnel.

Reproduction

Because sexual development and fertility depend on nutrition, and gestation and lactation require higher than average energy requirements, an ample supply of nutritious food speeds sexual maturity and promotes larger litters and increased survival. The time and length of the breeding season of ***T. talpoides*** varies

throughout its natural range. Ambient temperature is an important parameter. In most forested habitats, and for those populations at higher elevations and more northerly latitudes, breeding is once per year. Andersen and MacMahon (1981) set breeding times for ***T. talpoides*** 7 days from when the immediate environment is about 90 percent free of snow. Gestation for captive northern pocket gophers is about 18 days (Marsh and Steele 1992). Females bear their young in the spring, just before the onset of green foliage, and optimum conditions for burrowing.

Though relatively small and scrotal in position during the hot summer, the testes of pocket gophers enlarge during the colder winter temperatures. This, however, does not explain why in milder climates, where adequate forage remains relatively constant year-round, the northern pocket gopher can breed throughout the year. There, females have up to three litters annually.

Litters average five to six young, but range from one to thirteen. *"Northern pocket gophers are born sightless, hairless, and helpless, and weigh about four grams"* (Reid 1973). Female gophers have a strong maternal instinct, and very tenderly care for their young (Wight 1918). They all live peacefully together *"until increasing agonistic behavior forces dispersal"* after weaning (Teipner et al. 1983). This usually occurs 5 to 8 weeks after birth. At this time the juveniles have grown about one-third adult size, and can forage for themselves (Dixon 1924).

The temporary rising of the water table can drown gophers in their burrows after a rapid melting and runoff of a heavy snowpack, or a late season snowstorm can lead to births before the availability of green vegetation. The young-of-the-year can die not only from a lack of food, but from the cold and exposure after being wetted. This is especially true if the female gives birth in a nest created in the snowpack (Reid 1973).

Pocket gophers can begin sexual activity at 1 year of age (Henderson 1981), when they achieve both behavioral and physiological maturity. Because they lead solitary and subterranean lifestyles, they tend to mate with local residents. This may lead to reproductive incompatibility between subspecies, but studies cited by Chase et al. (1982) show that *"divergence at the chromosomal and morphologic levels can occur without concomitant genetic differentiation."*

Although the annual crop of pocket gophers generally has a 50:50 sex ratio, the adult population generally has more females. Adult females also form a greater percentage at low population levels, while adult males form a greater percentage during high population levels. The sex ratio of ***T. talpoides*** populations varies seasonally, with more males in the spring and more females in the summer and fall (Reid 1973). Case (1983) reports the exact opposite.

Population Dynamics

Gopher populations change perpetually. Their levels fluctuate naturally. The quality and quantity of available food contribute the most important influences to population density variations (Marsh and Steele 1992). Other factors include land use changes; altitude; the effects of weather on the habitat, i.e., on the soil and flora; the competitive interactions among neighboring individuals; and to a lesser extent, diseases and natural enemies. Ground disturbing activities generally increase the carrying capacity of an area for pocket gophers by increasing the supply of preferred foods and allowing a build-up of the resident population. Gophers reach their highest densities on friable, light-textured soils with high plant biomass, especially when the biomass consists of *"large fleshy roots, bulbs, tubers or other storage structures."* Probably due to conditions of the understory vegetation, populations of pocket gophers generally increase in stands less than 10 years old and in those greater than 80 years old, compared to stands in the 11- to 79-year old age classes (Scrivner and Smith 1981).

The relationship between pocket gopher population levels and damage to conifers depends on habitat conditions. Few or many gophers can cause a specified level of damage. Because large populations of gophers occur in meadows and grasslands, some researchers speculate that gophers feed on trees after utilizing the more preferred plants (Crouch 1979). In a montane sere grading from a sub-alpine forb meadow to a climax Engelmann spruce forest, Andersen and MacMahon (1981) find that the forb meadow produced the most usable plant energy, that the climax spruce forest could not meet the year-round energy requirements for northern pocket gophers, and that the intermediate seral stages probably could not meet the energy requirements for reproduction in females.

Volland (1974) finds that no consistent relationship exists between the abundance of pocket gophers and tree productivity, attributing this to the fact that *"the environmental factors governing tree growth are probably not the same factors conducive to gopher habitation."* He also reports that pocket gophers tend to have higher populations in central Oregon plant communities that support productive herbaceous understories. When disturbed or burned, these more xeric plant communities produce an increase in grasses and forbs through the early successional stages, and subsequently can support a further increase in the gopher population. However, in frost pockets, where succession to forest slows because of the harshness of the site, forbs grow well, and the endemic population of gophers can serve as the source for invaders into adjacent areas.

Although gopher populations do not directly correlate to elevation, they do so indirectly because soil depth, precipitation, vegetative composition and temperature depend partially upon elevation. Teipner et al. (1983) state that gophers at higher elevations generally grow larger than their counterparts at lower elevations if the upper elevation habitats have more nutritious forage.

Oftentimes, soil moisture levels limit the distribution of forbs, but dry soils and subsequently high soil temperatures, may limit pocket gopher densities more than does forb production. Mesic plant communities that support a rich understory of grasses, sedges and forbs, and do not have a water table within the rooting zone, can expect a moderate-to-high incidence of pocket gophers in natural or disturbed stands. The presence of, or incursion of rhizomatous plants, fleshy-rooted sedges and forbs following disturbances will increase the food source for pocket gophers, and stimulate their incursion into an area.

Herbage composition probably constitutes the most important habitat factor in determining gopher population thresholds, though weather probably constitutes the deciding factor in below threshold populations (Anderson and MacMahon 1981). Maximum population density and carrying capacity vary by site, but those of ***T. talpoides*** *"consistently peak at between 24 and 36 individuals per acre,"* conceding that there may be other factors that do not allow the population to reach this maximum level (Teipner et al. 1983). However, Chase et al. (1982) report 73 northern pocket gophers per acre *"in an exclosure of natural grass-forb range,"* but a maximum of only 19 per acre (47 per hectare) on *"free range, where the food supply was much less."* Marsh and Steele (1992) state that a high population in forest lands ranges from 15 to 25 ***Thomomys*** per acre (37 to 62 per hectare), with a patchy distribution pattern based on soil characteristics, moisture conditions and plant communities.

Unlike with other rodents, pocket gopher population density does not affect fertility rates, but population levels do vary according to mortality rates. Sullivan (1986) finds ***T. talpoides*** quite resistant to depopulation, with an average recovery ratio of over 69 percent per year.

Biologists generally separate gophers into two age classes, adults and juveniles, with no consistently reliable technique to age them beyond 1 year of age (Teipner et al. 1983). Adult northern pocket gophers generally average 2 years of age, and can live about 4 or 5 years if not preyed upon earlier (Turner et al. 1973). Their average longevity tends to increase at low population levels, and females generally live longer than males (Reid 1973). Young-of-the-year replace 75 percent or more of the population annually (Teipner et al. 1983), which indicates the normality of extremely high annual population fluctuations. Juveniles, therefore, form a greater percentage of the total population in the fall, but by spring, at 1 year of age, these same individuals appear indistinguishable from adults. High rates of survival do lead to population peaks beyond the habitat's carrying capacity, but population declines usually follow, sometimes *"with no apparent cause"* (Marsh and Steele 1992).

Dispersing subadults, i.e., juveniles, generally wander on the surface where they become easy prey (see page 29). ***T. bottae*** generally travel 300 to 400 feet (91 to 122 meters) (Chase et al. 1982). If gophers find a vacated burrow system, they will readily occupy it. Juveniles will sometimes *"occupy marginal habitats until better areas become available,"* as when other gophers die or immigrate (Teipner et al. 1983).

A rising water table can cause, or a snowpack can allow, gophers to migrate. Despite an acute homing instinct, they probably do not return to the same burrow system that they left. A snowpack allows easy dispersal, and because pocket gophers can burrow easily through snow, they can readily traverse obstacles without exposing themselves to predators on the surface. Chase et al. (1982) cite one ***T. talpoides*** that traveled 2,568 feet (790 meters) during a period of snow cover.

Effects Associated with Grazing

"Effects of pocket gophers on the range vary with size of the gopher population, nature of the habitat, season of the year, and range use by other animals. Because of this variability, findings from individual studies serve only as stepping stones toward an understanding of the role of gophers" (Turner et al. 1973). Gophers remain an integral component of rangeland ecology, and one cannot easily separate their influence on the ecosystem from other components of that ecosystem. Gophers affect the capacity of an area to support other animals by directly competing with wild and domestic ungulates, other herbivores and omnivores for the available forage, by covering additional forage that decays under mounds before other animals can utilize it, and by other modifications of the local habitat.

"There is no doubt that some competition for food exists between northern pocket gophers and other animals [livestock], but the degree of competition is difficult to evaluate because of our lack of knowledge about the specific plant use by each animal on a particular range...[especially since] a considerable percentage of the cattle's diet during the summer...[is] also found to be major food plants of northern pocket gophers on this same range" (Turner et al. 1973). If range grasses provide the primary forage prior to a gopher infestation, forbs will generally increase as competition from grasses decreases.

In general, gopher infested areas have a greater percentage of bare soil, which leads to accelerated rates of wind and water erosion, and a lesser percentage of vegetative cover, thereby decreasing forage production and delaying plant succession. Laycock and Richardson (1975) find that when they excluded ***T. talpoides*** from their study areas, fresh gopher mounds only covered 4 percent of the ground surface, but where they did not control the pocket gophers, fresh gopher mounds covered 11 to 18 percent of the surface area (see pages 14-17).

Gophers constantly produce patches of bare soil which create a continuous progression of microsites for early successional plants. The exclusion of gophers from an area will probably cause perennial grasses and forbs to supplant gradually the annuals that can no longer regenerate with the same frequency that they could without gopher activity. Therefore, with gopher exclusion, plant biomass, plant frequency and total cover increase (Williams and Cameron 1986), and total erosion decreases. Although *"prudent livestock grazing may provide an opportunity to further reduce rodent damage"* (Kingery et al. 1987), grazing pressure and soil fertility take on lesser importance (Kjar et al. 1984) than precipitation, which greatly influences the recovery of forest and rangelands from gopher infestations. Generally, areas of higher precipitation recover more quickly than areas where precipitation constitutes a limiting factor.

Gophers physically alter their environment by excavating burrows, creating mounds, burying vegetation, and of course, by eating vegetation. By selectively consuming certain preferred plants and burying others with mounds, gophers influence plant species density, composition, and vigor. They affect the total biomass in their habitat, but have little effect on overall species composition (Williams and Cameron 1986). Selective aboveground feeding suppresses the growth of some plant species, and stimulates the growth of others, such as those that sprout.

Julander et al. (1959) find that winter casts had a more destructive effect on grass seedlings than mounds did (see pages 14-17). All these effects cause a spatially clumped regeneration of annuals, and create a mosaic of different successional stages within the area inhabited by gophers. Such diversity allows plant combinations to exist together that would not do so without the constant disruption of the soil by gophers, and also delays plant succession toward a climax vegetative type.

In contrast to this scenario, Tevis (1956) cites the case of a ridge in northwestern California that *"originally was covered with a turf of Idaho fescue* ***(Festuca idahoensis)*** *which prevented the spread of conifers."* Overgrazing at the turn of the century disturbed this turf enough to allow the invasion of *"deep-rooted and bulbous plants,"* which allowed an increase in the pocket gopher population. The large amounts of exposed soil provided an ideal seedbed for a bumper crop of red fir cones in 1951. The resultant seedlings suffered high mortality, but enough seedlings survived *"to indicate that much of the range is destined to become forest."*

In his study of mima mounds, Cox (1989) finds that northern pocket gophers have a significant effect on the Columbia Plateau grassland ecosystems by consuming intermound food items in preference to food items growing on the mounds, thus controlling the vegetative composition and the distribution of plants on the mounds and in the intermound areas. He also finds that their diet consists of 97 percent forbs and 3 percent grasses, with lupine ***(Lupinus caudatus)*** comprising 71 percent of all shoot matter consumed.

Kingery et al. (1987) report a direct relationship between ground cover and pocket gopher damage. In their study in Idaho, gophers caused less aboveground damage and more belowground damage under a moderate to heavy grazing regime, but that aboveground and belowground gopher damage was greatest on rangelands subjected to low and intermediate levels of grazing, probably because the gophers capitalized on the more favorable vegetative habitat, i.e., lush forbs and grasses, during the growing season. Gary W. Witmer, (1994, personal communication) observed that heavy grazing by sheep to control brush on reforestation units can reduce gopher density by two-thirds.

Gophers have a greater overall effect on forage utilization on poor rangeland than domestic livestock do, because as a range deteriorates, the percentage of high quality perennial grasses decreases, and annual weeds and perennial forbs occupy their growing space. These latter plants provide inferior forage conditions for wild and domestic ungulates, maintain poor range in a poor condition but supply ideal food items for gophers.

Since gophers consume vegetation 12 months of the year in the same locality, and ungulates, both domestic and wild, only graze for a portion of the year in the same locality, the consequences of gopher feeding assume greater importance than their small size may suggest. Unlike domestic stock that travels over a range, individual gophers must survive on the plants that grow within their territory for 12 months of the year–unless they migrate to a different area. For example, Case (1989) states that ***G. bursarius*** reduced forage yields 21 to 49 percent on four sites in western Nebraska rangelands.

Gopher activity can affect highly productive sites more than low productivity sites. Reichman and Smith (1985) find that gophers select territories within habitats containing the highest plant biomass, and proceed to reduce the root and stem portions by over one-third, preferring the tap-rooted species to the diffuse-rooted ones. However, if range vegetation remains in fair to better condition, ungulate grazing causes conditions less favorable to gophers. Because the higher productivity of the area allows the growth of more palatable vegetation for wild and domestic ungulates, there is less space for seral vegetation desired by pocket gophers.

Gopher activity under mat.

Because gophers tend to accelerate range deterioration on overgrazed range, gopher control will allow poor ranges to improve over time. Although heavy grazing does not necessarily lead to an increase in the gopher population, it may happen on overgrazed ranges. This perpetuates transitory and annual plants, which cause the range to remain in poor condition. In many cases, though, range managers can moderate gopher damage or avoid it by identifying the gophers' probable response to habitat changes, and by promptly applying control measures. Generally, after the reduction of a gopher population, deteriorated rangelands tend to improve, but gopher control on a well-managed, productive rangeland will have little effect on overall range productivity.

Effects on Soil

"Ernest Seaton Thompson has called the pocket gopher, 'The Master Plowman of the West' " (Wight 1918). *"Pocket gophers were a dynamic force in determining the biochemical attributes of the North American prairie lands; the burrowing activities of such fossorial rodents may provide an explanation for the genesis of these prairie soils. [Bison **(Bison bison)** grazed and trampled the dense prairie vegetation and accelerated the forb growth on which the gophers thrived.] The gopher, in turn, worked the soil, thus increasing soil fertility and stimulating vegetative growth, increasing food for the bison"* (Chase et al. 1982).

Gophers have impacted soils in the Northwest in both positive and negative ways since the Pliocene era. The activity of fossorial animals, including gophers, influences the distribution of the soil's primary particles (sand, silt, and clay), that is, the fines tend to end up on the surface and the heavier particles settle. In addition to particle size distribution, gopher activity also affects compaction and porosity, which influences biological activity, which influences the amount and distribution of chemicals within the soil (Sejkora et al. 1985).

On the positive side, gophers mix and aerate the soils, and can decrease bulk density in clay soils (Laycock and Richardson 1976). Since the clay content of soil affects its structure and stability, gophers also affect the soil's erodibility. By transporting subsurface minerals to the surface and combining different soil layers, gophers deepen effective rooting depth, improve infiltration rates, maintain tilth, lower bulk density and increase noncapillary porosity, all of which benefits the development of soil and plant growth over time. Pocket gophers also loosen up and soften soils that ungulates and/or machinery have previously compacted.

On the negative side, gophers consume above and belowground portions of the area's biomass, allow the desiccation of roots exposed to the feeding burrows and the drying of the soil in the burrows themselves, and subject the mounds to wind and water erosion. Since gophers reduce the root biomass, they also reduce the ability of roots to pump water from the soil profile, and transpire it into the atmosphere, which causes a mosaic of differing moisture regimes within the plants' rooting zone. Although gopher activities may maintain soil moisture content in some respects, they can also reduce it. Sejkora et al. (1985) demonstrate in their study that vegetated plots without gophers showed moisture stress in mid-June, which *"progressed to nearly complete senescence by late August."* Their vegetated plots with gophers *"did not begin to show marked moisture stress until mid-July, with the majority of the vegetation remaining green until frost in early October."* The results of experiments such as these can vary depending on soil type, slope, plant cover, and the sampling location of the moisture content measurements, i.e., along side or beneath mounds.

Pocket gophers prefer light-textured, very porous soils with good drainage, but soil characteristics per se do not attract or limit gopher occurrence. Kjar et al. (1984) find that the plains pocket gopher ***(G. bursarius)*** occurred only in soils with less than 70 percent clay and greater than 40 percent sand. The silt content had no apparent effect on gopher distribution.

Sullivan et al. (1987), in trying to determine if soil texture limited the distribution of three species of voles and the northern pocket gopher in relation to the incidence of damage, concluded that *"except for the clay/loam soil type which had fewer...orchards with pocket gopher damage than the sand/loam type, soil texture appeared to have little effect on supporting vole and pocket gopher populations in an orchard environment."* They also state, *"in an essentially dry climate, irrigated orchards...are likely to provide productive grassland/forb habitat for voles and pocket gophers...Our assessment of soil texture and distribution of rodent damage indicated little difference among the various soil types."*

T. talpoides favor soils with less than 25 percent rock over 1/4-inch (6 millimeters) in diameter, and limited amounts of rock greater than 1 inch (2.5 centimeters) in diameter (Reichel 1986). Gophers do occupy rocky soils, but generally avoid those that contain more than 10 percent rock in the top 8 inches (20 centimeters) of soil (Case 1983).

In their study of Mima mounds on the Columbia Plateau, Cox and Allen (1987) suggest that *"the tunneling of pocket gophers in search of fleshy-rooted plants in the stony intermound soils is the primary mechanism that forms and maintains the sorted stone networks."* Cox (1989) states, *"Translocation results from the backward displacement that accompanies outward tunneling from centers of activity. By mining soil from intermound areas, this translocation also contributes to the formation and maintenance of the inter mound scablands...Formation of these beds may result from the collapse of tunnels dug beneath them [by gophers] in search of highly preferred food plants."* In other words, the particle size distribution in the soils varies between mound and intermound areas because gophers mix the soil and redistribute the rocks. Many generations of pocket gophers dig outward from the Mima mounds, which causes the overall movement of soil and smaller stones toward the mound itself, and causes it to rise in elevation. They generally move those stones and rocks less than 1 inch (2.5 centimeters) in diameter and some larger ones, but the latter, including all those greater than the diameter of the burrow, generally settle, until they sink to the base of the mound, or lay exposed on the surface in the intermound areas.

Pocket gopher tunneling under these stone nets ceases after the gopher activity and subsequent erosion removes the fine soil materials and leaves only stones larger than the gopher can conveniently move. Mima mound soils, therefore, end up having a lower bulk density, higher organic matter content, and higher permeability, all of which allow these mounds to produce two to five times more herbage than the intermound soils (Turner et al. 1973).

Chemical properties of the soil do not limit the occurrence of gophers. Even though no apparent relationship exists between mounding activity and nutrient levels (Gates and Tanner 1988), soil chemistry indirectly does affect plant composition and biomass production, which in turn, may affect gopher populations. Soil fertility may affect the occurrence or nonoccurrence of preferred food plants, so even though pocket gophers consume a wide variety of plant species, the absence of suitable vegetation can deter them from occupying otherwise suitable soils.

"A field full of pocket gophers is perpetually dynamic, with new excavations and the plugging of old burrows going on day and night" (Reichman et al. 1982). However, *"no studies have accurately measured all long term soil-moving by free-living gophers"* (Huntly and Inouye 1988). Steuter et al. (1990) find that five to 55 ***(G. bursarius)*** per acre (12 to 136 per hectare) in a prairie environment, with mounds covering 10 to 25 percent of the area, bring 12 to 83 tons (11 to 75 metric tons) of soil per year to the surface. Reichel (1986) reports that ***T. talpoides*** disturbed 14 to 24 percent of the surface in his alpine study area. Huntly and Inouye (1988) cite a study (no species mentioned) in which *"mounds and earth cores may cover as much as 25-30% of the ground surface,"* and can bring to the surface over 270 pounds of soil per acre (315 kilograms per hectare) from July through September, and another which shows that the gophers (no species mentioned) backfilled 41 to 87 percent of the excavated soil into unused burrows. Concerning the latter, they state, *"The limited data on backfilling indicates that it may be ecologically significant."*

Henderson (1981) reports that one pocket gopher (species unmentioned) could transport 2-1/4 tons (2 metric tons) of soil to the surface each year, and Willis (1981) reported that *"a single gopher"* (species unmentioned) can displace as much as 3 tons (2.7 metric tons) of soil to complete its burrow system. Grant and McBrayer (1981) cite ***Thomomys spp.*** as bringing over 34 tons of soil per acre (76 tonnes per hectare) per year to the surface, but do not mention the number of resident pocket gophers per acre.

Although population densities of ***T. talpoides*** vary, Anderson and MacMahon (1981) report maximum densities of 24 to 36 per acre (59 to 89 per hectare) in their Utah study–a range of eight to 20 gophers per acre (20 to 49 per hectare) in northeast Oregon falls within reason. Assuming the 3 tons per acre (6.7 metric tons per hectare) figure, eight to 20 gophers would transport 24 to 60 tons of soil per acre (54 to 134 metric tons per hectare) to construct their burrow systems. Assuming 41 to 87 percent of that is backfilled, we can calculate that a range of 3 tons (2.7 metric tons) (13% x 24 tons) to 35 tons (32 metric tons) (59% x 60 tons) is pushed to the surface each year. Assuming the 2-1/4 tons per year, eight to 20 northern pocket gophers would transport 18 to 45 tons (16 to 41 metric tons) of soil to the surface per acre per year.

Light-textured, porous soils provide the best drainage and also allow for the best exchange of gasses. Since gopher burrows form a closed system, interburrow air circulates very little and the percent moisture remains fairly constant.

Gophers have adapted to a subterranean atmosphere that has 25 to 30 percent more carbon dioxide and 5 to 20 percent less oxygen than the atmosphere on the surface. Soil flora account for some of these differences (Turner et al. 1973). However, atmospheric oxygen must still diffuse downward and exhaled carbon dioxide must diffuse upward to the surface. Therefore, gophers generally avoid soils with high clay content, or those that stay continuously wet, because these soils have poor gas exchange capability. Teipner et al. (1983) state that *"gophers may live in soils where mean moisture content ranges from less than 10 to those more than 50 percent."* However, I think they meant that optimal moisture content ranges from 10 to 50 percent. Reichel (1986) also states that northern pocket gophers favor soils with less than 50 percent ground moisture.

Gophers also affect surface runoff and infiltration, but the degree varies by soil type and slope. Soil from castings produced during the winter has fine particles that tend to seal the surface layer of soil and thus reduce infiltration and increase runoff (Julander et al. 1959). Soil generally has a lower moisture content for a depth of 6 inches (15 centimeters) directly below mounds (Turner et al. 1973), probably because of the decrease in infiltration. However, infiltration and porosity in large-scale, gopher-infested areas generally increases, probably due to the resultant aeration and loosening of the soil and the addition of irregularities in the soil surface that allow better penetration of precipitation. Sejkora (1985) finds *"the largest overall increases in infiltration were due to collapse of near-surface tunnel systems, [and] mounds of cast soil were observed to form small dams, behind which water was temporarily stored. Meanders around such obstructions eventually developed. The corresponding increase in residence time of water on the surface should lead to a proportional increase in infiltration into the profile."*

Gopher burrows also affect water penetration by serving as conduits for snowmelt and other surface water. Areas of ungulates. Therefore, more water remains in the soil profile longer compared to areas of no gopher activity. Also, since surface water carries naturally-occurring organic acids and other solvents, it helps break down subsoil particles and subsurface rock, which results in increased mineralization and fertility.

The soil in gopher mounds differs in both physical and chemical properties from undisturbed surface soil (Huntly and Inouye 1988). The constant burrowing and displacement of soil by pocket gophers increases the soil's overall permeability and porosity, but accelerates erosion and natural sedimentation. *"The rich sediments of valley bottom lands have resulted from erosion at higher elevation in past geologic times; to this process, pocket gophers may have been a contributing factor"* (Stewart and Baumgartner 1980).

The subsurface soil in mounds and castings (most of which probably originates in the top 6 inches (15 centimeters) of the soil mantle) generally differs from the surface soil on which the gophers deposit it. Consequently, its settling and dispersing on the surface modifies the original soil mantle. Also, because of the larger pore spaces in mound soils, their water holding capacity is much greater than the surrounding surface soils. The higher concentration of fines in the mounds, plus the ability to soak up water rather than shed it, sometimes allows the consistency of saturated mounds to resemble that of peanut butter (personal observation).

Since mound soils have a higher clay content, they also have a higher cation exchange capacity, though actual capacities vary by soil type. Nitrogen, sodium, and phosphorous levels do not vary much from adjacent soil not in mounds (Grant and McBrayer 1981), but mound soils do have higher concentrations of magnesium, calcium, and exchangeable potassium (probably from buried vegetation). However, the highly mobile potassium ions leach out rapidly. Reichman (1988) reports that plants growing on mounds have a higher mortality rate than those not growing on mounds, but those that survive grow larger and produce more seed, *"suggesting that the openness of the mounds outweighs their relative nutrient deficiency as a factor in plant productivity."*

Gophers prefer areas with high soil nitrogen and high primary productivity (Huntly and Inouye 1988). Since available soil nitrogen heavily affects the growth of plants and the primary productivity of the site, and since soil nitrogen generally decreases with depth of soil, the deposition by pocket gophers of tons of nitrogen poor subsurface soil on the surface creates a patchy redistribution and mixing of available nitrogen. This constantly changing vertical and horizontal distribution of soil nitrogen affects nutrient availability, plant growth, and biomass. The surface soil layer then suffers a net loss of nitrogen per unit of plant biomass, and the total plant biomass and species composition changes from what that same piece of ground would produce without gopher activity. The deposition of urine and the decay of fecal matter and other waste material in the food

caches and unused burrows, and buried surface vegetation, add total nitrogen and phosphorous to the soil, and increase overall fertility (Laycock and Richardson 1975). The "green manure" effect caused by burying live, aboveground plants accelerates in the fall when young-of-the-year establish their burrow systems, and all gophers search out more food to cache for the winter (see pages 8-10).

The exposure of bare soil in areas occupied by pocket gophers relates closely to ground vegetation consumed. Pocket gophers, if they have the choice, burrow under areas with greater plant biomass, both above and below ground. They reduce that biomass by removing the tap-rooted species at a faster rate than the diffuse-rooted ones. In general, gophers tend to decrease the population of the plant species upon which they feed, maintain the population of species that need exposed soil upon which to germinate and grow, and influence these plants in such a manner that they also affect the population of invertebrate herbivores.

In reference to the latter, Huntly and Inouye (1988) also find that chemically eliminating below ground or aboveground feeding invertebrates greatly increases mound building by gophers, suggesting that *"competitive interactions between herbivore groups...probably are mediated through changes in the plants available as food."*

Huntly and Inouye (1988) also *"found gopher mound density to be a strong indicator of grasshopper density,"* as opposed to other parameters measured, *"including mean and variance of plant biomass, cover, diversity, and nitrogen content and the mean and variance of soil nitrogen."* Since grasshoppers oviposit in open soil, egg and nymph survive best in mound soils. Also, because nymphal and adult grasshoppers are sensitive to cold and wet weather, their survival and growth depend not only on warm, dry weather conditions, but heterogeneous vegetative communites that pocket gophers help generate.

Mounds function not only as different resource sites, but new colonization sites as well. The transportation of subsurface soil to the surface, most of it from the shallow feeding burrows within the plants' rooting zone, affects the structure of the local habitat and creates micro habitat changes that generate prime conditions for pioneer plants to germinate and grow. Mounds and castings provide different micro environments for germination than do organic litter-covered sites. Mounds and castings also bury seeds, which protects them from predation by other rodents and birds. Although these microenvironments may provide suitable sites for conifer regeneration, the germinants that result also provide a very accessible food source for gophers.

T. talpoides create more favorable growing conditions on the surface by enhancing seed germination and plant establishment. Their mounding brings to the surface inorganic material useful for plant growth, seeds and mycorrhizal inocula from subsurface layers. The mixture of organic matter in the mounded soil also increases the water-holding capacity, which helps the gopher to maintain a constant humidity in the burrow. Mounds also affect the burrow environment by influencing such temperature factors as heat transfer, radiation, reflection and absorption on the surface.

Gophers modify their local habitat and affect herbage composition directly by burying litter, exposing soil, and selective feeding. This causes an increase in localized evaporation, and because gophers eat an appreciable amount of plant biomass, they also cause a decrease in total transpiration. Although such changes do not significantly affect the total area's productivity, they do influence seed germination, seedling establishment, and the composition and distribution of plants. Probably caused by an increase in nutrients, the immediate areas around mounds have significantly increased production that more than offsets the localized bare areas of the mounds themselves, suggesting that *"the longer-term activities of gophers result in increased rates of soil development and higher soil fertility"* (Huntly and Inouye 1988). Although an increase in total herbage production may not always follow as a result of an increase in fertility caused by pocket gopher activity, Laycock and Richardson (1975) speculated that *"the disturbance to the vegetation by the burrowing activities plus the material harvested and consumed by the gophers offset the increased fertility of the soil."*

Burrowing animals can determine early successional patterns. In mesic habitats, gophers and ants *"initiate reestablishment of plant communities"* and *"may regulate succession"* by mixing soil layers and by transporting mycorrhizal inoculum and plant propagules, which are *"essential components in fostering desirable, diverse communities in a wide array of habitats"* (Allen et al. 1984). ***T. talpoides*** strongly affect the dynamics and composition of plant populations in volcanically disturbed areas *"through their soil-disturbing activities,"* thus being *"an important agent in determining the pathway of succession."* Their mixing of old soil and tephra modifies the *"substrate physically, chemically and biologically,"* all of which influence plant populations and plant succession (Andersen and MacMahon 1985a).

Although most land managers would place pocket gopher activity in a generally detrimental category, the posteruption successional trends evident in the Mount St. Helens eruption zone have proven otherwise. The surviving pocket gophers altered the tephra habitat,thus hastening the rejuvenation of the vegetative communities, and the faunal communities as well (Allen et al. 1984).

Feeding Behavior

Wang et al. (1986) describe eight components of pocket gopher feeding behavior: **1)** creating an exit hole; **2)** exploring; **3)** pulling food into burrow, which sometimes may contain some non-palatable parts; **4)** separating the food items from the nonfood items, and consuming or caching the food (pocket gophers are quite thorough in recovering edible parts); **5)** repeating search for food items; **6)** closing the hole; **7)** sampling, gnawing and eating (probably all done at the same time because gophers chew and swallow food, not lick it); **8)** depositing feces (usually in a dump within the burrow system or left scattered around). However, Andersen and MacMahon (1981) report that geomyids practiced coprophagy. Gophers usually urinate in set locations.

Most researchers agree that gophers are herbivorous, but Gottfried and Patton (1984) find that gophers consume between 8 and 19 percent of their diet in insects. Case (1983), though saying that gophers are *"strict herbivores,"* also states that they do sometimes ingest animal material (generally insects) incidental to eating vegetation. In his study of pocket gopher stomach contents, Cox (1989) found minimal amounts of *"arthropod fragments."*

Pocket gophers locate their food by odor. Hungerford (1976) finds that when the northern pocket gophers in his study ran short of food, they responded to injected odors within 10 to 15 seconds. Although other researchers do not mention fungi as a component of pocket gopher diets, Maser, Trappe and Ure (1978) do. In particular they state that *"animals that feed on hypogeous mycorrhiza-forming fungi apparently detect the fruiting bodies by odor. Each hypogeous fungal species produces a particular odor, which intensifies and becomes more penetrating as spores mature within a fruiting body. The digestible tissues of fruiting bodies have a high water content and also contain substantial protein, carbohydrates, vitamins and minerals."* In their comparison of pocket gopher diets in Colorado and Oregon, Burton and Black (1978) state, *"Of all available foods, the most succulent foods were preferred. These conclusions may apply to gophers throughout their range."* Mushrooms certainly qualify as both odoriferous and succulent.

Maser, Trappe and Nussbaum (1978) find that ***T. bulbivorus, T. townsendi,*** and ***T. talpoides*** consume fungi, and since the fungal spores do not lose viability in the gophers' digestive systems, they accumulate in the burrow systems. The authors cite a case in Linn County, Oregon where, even though *"largely surrounded by forest,"* conifers did not invade a meadow except at one end *"where **T. mazama** activity had become concentrated throughout the year...Gophers eating the appropriate fungi in the forest, then moving into the meadow and defecating in their fecal chambers, could easily build up a localized spore concentration for mycorrhizal inoculation of conifer seedlings."*

Pocket gophers do not always exhibit consistent feeding behavior, which varies greatly by individual gopher, habitat type, vegetation composition, herbage production and snowpack. The energy requirements of ***T. talpoides*** and the relationships between forage availability in different environments along sucessional gradients demonstrate that northern pocket gophers display catholic food habits, eating almost all nonnoxious roots, but showing much more preference in choosing aboveground parts (Andersen and MacMahon 1981). Some even say that gophers grow their own food, i.e., cause soil conditions that favor the continued germination and growth of the plants that they prefer to eat (see pages 14-17).

Being adaptable in their feeding habits–food availability heavily determines diet–pocket gophers respond to changes in food availability by adjusting their foraging behavior to correspond to the phenology and abundance of the accessible vegetation (Burton and Black 1978). Although *"there are few plants which gophers will not eat"* (Willis 1981), particular gophers show marked preferences for obtainable vegetation. Cummins (1975) finds that certain individual northern pocket gophers *"ate significantly greater amounts of all [ponderosa pine] seedlings"* than did other individuals. Each gopher selects varying amounts of different types of food items depending on its personal preferences, plant succulence, time of year and habitat, but usually consume legumes, plants with high water content, and bulbous roots–especially ***Lomatium*** (Cox 1989)–in preference to fibrous plants such as grasses, even if grass forms a major component of the gopher's habitat.

T. talpoides consume a greater volume of food and gain more weight during periods of vigorous activity, such as when building or repairing their burrow system. In a laboratory setting, Hungerford (1976) finds that a normal 75 gram ***T. talpoides*** consumes a daily average of 52 grams of food, but during heavy activity periods, consumes approximately its own weight in food per day.

Although pocket gophers can utilize all plant parts, they prefer the green succulent portions of perennial forbs when available, and vary their diet seasonally, depending on species availability. Grasses rarely form greater than 30 percent of their diet (Teipner et al. 1983). In a laboratory study, Tietjen et al. (1967) shows that even if pocket gophers survives on certain grasses, they lose weight, *"indicating a marginal diet."* However, when gophers do consume grasses, they usually eat the parts high in water content, and/or eat them during the dormant season when other preferred foods are unavailable. Gophers damage grass stands by consuming, from below ground or under snow, the root crowns and stem bases where the plants store much of their food reserves (Julander et al. 1959).

Gophers often eat belowground parts of plants without regard to species. They seem more particular about aboveground parts, and although aboveground parts of grass provide only a marginal diet, their corms and rhizomes do provide a subsistence diet (Gottfried and Patton 1984). Areas that supply a marginal diet for gophers reduce the ability of that population to survive, and a decrease in population will probably result.

Cox (1989) finds that in early June, grass only contributes 2.4 percent of the shoot matter consumed by ***T. talpoides*** in his study area in north-central Oregon. Lupine constituted 70 percent of the shoot matter consumed, with other forbs constituting another 27 percent. *"Buckwheat, probably all **Eriogonum heracleoides**, and yarrow **(Achillea millefolium)**, were other mound dominants that were taken in significant amounts."* Laycock and Richardson (1976) report that northern pocket gophers preferentially consumed and practically eliminated dandelion ***(Taraxacum officinale)*** from their subalpine grassland study area.

Thomomys spp. prefer plant communities that support *"lush stands of rhizomatous and/or fleshy-rooted forbs"* (Volland 1977). Gophers easily consume roots and underground stems from their feeding burrows during the night or day. However, they generally gather food items from the surface during the evening rather than during the daylight hours. They may feed on surface vegetation near a burrow entrance, but oftentimes drag plant parts into their runways to be eaten or cut into smaller pieces, stuffed into their cheek pouches, and taken deeper into their burrow system to be eaten or cached. Pocket gophers empty their cheek pouches by applying pressure with their forefeet to the sides of their cheeks and face, and push the food items out in a sweeping motion (Verts and Carraway 1987).

Cox (1989) cites the strong seasonal cycle in the utilization of roots versus shoots in the ***Thomomys*** diet, i.e., heavy in shoots during the growing season and roots during the dormant season. He also cites an example of ***T. monticola*** that was the direct reverse. From a different angle, Anderson and MacMahon (1981) say that for ***T. talpoides,*** regardless of how preferable *"the food item might be, it seems reasonable to expect that only those belowground food items actually noxious would be ignored, given the high [energy] costs incurred in procuring them."* In all likelihood, individual gophers, or certain populations, have food preferences that defy the consistency sought by researchers (see pages 33-34).

Burton and Black (1978) find that ***Mazama*** diet in the pine region of southcentral Oregon directly relates to food availability and succulence. Their study area consisted of 36 percent grasses and 57 percent forbs. Of the forbs, 90 percent were annual and 10 percent perennial. The latter were not abundant enough to provide a dependable food source. In July, when all foods abound, the order of preference was perennial forbs, grasses, and finally annual forbs. They also find that the ***T. mazama*** consume aboveground forbs for 40 percent of their annual diet (taken mostly during the growing season), grasses for 32 percent (taken mostly during the dormant season), and woody plants for only 4 percent. Although they find that roots comprise almost one-quarter of the ***T. mazama*** annual diet, roots form almost one-half of their diet in March. Keith et al. (1959) and Tietjen et al. (1967) report that ***T. talpoides*** prefer forbs to grasses, and only consume woody plants when their preferred foods did not grow, generally during the period from November through May.

Though many researchers state that pocket gophers least prefer woody plants, others cite the use of ceanothus, ribes and other shrubs (Teipner et al. 1983). Hunter et al. (1980) report that ***T. bottae*** fed heavily on both native and planted shrubs in their Northern Mojave Desert study area. Turner et al. (1983) report enlarged chambers in burrows beneath rabbitbrush ***(Chrysothamnus parryi)***, attributing those areas to favorable micro habitats for northern pocket gophers, and I have encountered large numbers of shallow burrows beneath patches of common snowberry ***(Symphoricarpus albus)*** in northeast Oregon. From fall through spring, food preferences again reflect availability, i.e., fewer forbs and more tree parts.

Injury to Trees

"Gophers feed on stems, roots, and to a lesser extent, foliage of seedlings and saplings of most conifer species" (Crouch 1977). They kill or injure tree seedlings by debarking, pruning roots, or by pulling entire seedlings below ground. Northern pocket gophers consume ponderosa pine parts in the following order of preference: stem, roots, needles, and terminal bud. They usually eat a greater percentage of small seedlings than of larger ones (Cummins 1975).

Since most gopher feeding activity takes place under ground, it can occur throughout the year. Debarking of trees up to 7 feet (2 meters) high (Barnes 1973) and clipping off seedling stems often occurs under snow cover. Gophers eat roots at all times of the year, but mostly during the winter and spring. The drying effects of roots exposed in burrows and the possible burying of seedlings by casts or mounds *"usually are of minor importance in comparison with other types of damage"* (Barnes 1973).

Gophers do most of their feeding on conifers from late fall through early spring when the green succulent vegetation they prefer is not available. Tunneling through snow also gives gophers access to trees and other forage growing in areas not easily accessible during the snow-free seasons and in areas where shallow soil cannot support a burrow. Trees become

more vulnerable during this period because gophers have access not only to the roots but also to the stem and foliage to the height of the snow cover, all while safely unexposed to predators on the surface. *"The presence of winter casts around injured trees indicated that virtually all gopher damage was done by animals burrowing through snow"* (Barnes 1978).

Gophers kill trees by consuming the entire root system or by so weakening the anchorage of the tree so that it just topples over or a strong wind blows it over. Also, under the cover of snow, gophers access and consume the thin, smooth, succulent bark of young trees, and kill them by girdling, or in the case of very small seedlings, completely severing them. Pocket gophers leave a relatively smooth gnawed surface, with 1/16-inch-wide (1.5 millimeters) toothmarks, or they gnaw deeply into the stemwood and leave *"a sculptured effect"* (Marsh and Steele 1992).

The girdling damage of voles also leaves a similar gnawed surface on young trees. But since voles have smaller teeth, they leave a fuzzy surface, and toothmarks that measure about 1/32-inch (1.8 millimeters) wide. Porcupines, whose gnawed surface also resembles that caused by gophers, leave toothmarks that measure about 1/8-inch (3.2 millimeters) wide, and bits of shredded bark on the ground below where they were feeding. Rabbits, voles, and porcupines *"rarely gnaw into the wood"* (Marsh and Steele 1992).

The impacts of gopher depredation on coniferous trees becomes less severe as the trees increase in height and diameter. However, trees larger than seedlings often incur gopher damage over a period of years. Aboveground symptoms, such as foliage color change, tilting, or being windthrown, do not appear until it is too late to initiate gopher control practices.

Long-term feeding attacks on the tree roots and stems cause a weakening of the tree and divert growth energy to callus tissue rather than to new roots or to increases in stem diameter. Besides suffering a reduction of growth and subjecting areas of exposed wood to subsequent decay, fatal injury does not occur on sawlog-sized trees unless they suffer consistent and repeated feedings over several years. Gross and Laacke (1984) find that gophers feed actively on roots of large trees below where the thick furrowed stem bark turns into thin succulent bark, and found callus tissue on several major roots, which indicated successive feedings for many years. They also documented the largest tree ever windblown because of persistent gopher feeding on its roots, a 37-inch (94-centimeter) dbh red fir ***(Abies magnifica)***, growing at 6,200 feet (1,900 meters) in northeast California.

Besides ponderosa pine, gophers limit the natural regeneration of other species, such as aspen ***(Populus tremuloides)*** (Castor and Whitham 1989), Douglas-fir ***(Pseudotsuga menziesii)***, lodgepole pine ***(Pinus contorta)*** and cause damage to Engelmann spruce

Gopher damage.

(Picea engelmannii) (Barnes et al. 1970), grand fir ***(Abies grandis)***, western larch ***(Larix occidentalis)*** and western white pine ***(Pinus monticola)*** (Crouch 1979).

Although gophers may continuously feed on planted conifers annually for 10 or more years (Crouch and Hafenstein 1977), Barnes (1978) reports little research on the disease susceptibility of trees following repeated feedings by gophers. The long-term effects of reduced stocking due to the death of girdled or root-shorn trees, years of potential growth lost, costly site preparation, and replanting of understocked stands cause most of the gopher damage to conifer plantations. In essence, rotation ages became meaningless in plantations where gophers destroy the newly created stands before they can become fully established (Minore 1978).

Gopher-eaten tree roots.

Gopher-eaten Engelmann spruce.

Authorities Governing Animal Damage Management Activities on National Forests

Forest Service Manual (FSM) 2601 (WO Amendment 2600-91-7 of 9/24/91) mentions the major laws and Executive Orders that provide the authorities to manage the wildlife, fish, and plant resources on National Forests. Under 2601.2e, ***Economic Losses From Plant and Animal Pests,*** it states:

> *Programs of the Department will seek to alleviate damage by plant and animal pests to...forage, forest...and their habitats. Departmental agencies, through management and research programs, will develop or assist in developing new techniques and methodologies for the prevention of damage to agricultural or forestry production...Another goal is to reduce depredation on...forests...under registered control methods. When control is necessary, the offending animals will be removed as humanely and efficiently as possible, provided such action does not threaten the continued existence of any species.*
>
> *On lands administered by the Department, direct...rodent damage control programs will be coordinated with other Federal and State agencies. [The Reforestation and Animal Damage Control Forester in the Supervisor's Office has this responsibility.]*
>
> *The Department will promote the concept and use of integrated pest management practices in carrying out its responsibilities for pest control.*

In addition to the laws and Executive Orders listed in FSM 2601, the following authorities listed in FSM 2650 also apply on National Forest System lands:

- ❑ *The Animal Damage Control Act of March 2, 1931 (7 USC 426-426b), as amended by the Rural Development, Agriculture, and Related Agencies Appropriations Act of 1986 (PL 90-190) identifies the responsibilities of Federal Agencies for animal damage management on Federal lands, and authorizes the Animal and Plant Health Inspection Service - Animal Damage Control Division (APHIS-ADC) to provide animal damage management services, to maintain technical expertise for evaluating and recommending animal damage management techniques, and to conduct forest and range animal damage research.*
- ❑ *Executive Order 12342 of January 24, 1982 permits the use of chemical toxicants registered by the EPA for predator damage control on Federal lands.*
- ❑ *A Memorandum of Understanding between APHIS and the Forest Service of April 5, 1990, outlines the cooperative approach to animal damage management on National Forest System lands. Both agencies agree that they have a mutual responsibility for limiting the damage caused by wildlife.*

It is Forest Service policy to:

- ❑ Conduct animal damage management activities when necessary to accomplish multiple-use objectives.
- ❑ Recognize APHIS as the agency with expertise in animal damage management.
- ❑ Limit control to depredating individuals or populations whenever possible.
- ❑ Emphasize an integrated approach to animal damage prevention and management, considering a full range of methods.
- ❑ Use only pesticides (following label instructions) that are properly registered (federal and state) for animal damage management and that conform to USDA policies.
- ❑ Ensure that only certified pesticide applicators use or supervise the use of restricted-use pesticides on National Forests, and that all people involved in animal damage management comply with applicable federal and state regulations.
- ❑ Initiate an Endangered Species Act, Section 7 consultation when a Biological Evaluation (BE) determines that a proposed control project *"may affect"* any T&E species. NEPA documentation approval will only follow a *"no adverse effect"* determination by the USDI Fish and Wildlife Service.
- ❑ Weigh social, aesthetic, and other values along with economic considerations when evaluating the need for, and the conducting of, animal damage management programs.
- ❑ Develop and conduct all animal damage management programs in coordination with all applicable federal and state agencies, and in accordance with the Forest Land and Resource Management Plan.

As per FSM 2650, it is the responsibility of the Forest Supervisor (through the Forest Staff) to:

- ❑ Ensure that site-specific NEPA requirements for proposed animal damage control activities are compatible with Forest Plan direction.
- ❑ Approve rodent population control projects, including the use of pesticides.
- ❑ Ensure that all employees who conduct Animal Damage Management (ADM) activities maintain their expertise in planning, including silvicultural prescriptions, NEPA compliance and operations.
- ❑ Ensure that the control of non-game species (including rodent) damage on National Forest System lands is coordinated with other Federal and State agencies.

The ***Land and Resource Management Plan, Wallowa-Whitman National Forest*** contains the following pertinent references to animal damage control:

- On page 4-3, the Protection Forest Management Goal states, *"To control Forest pests to levels that are compatible with resource objectives."*

- On page 4-48, the Standards and Guidelines under Silvicultural Systems state, *"Promote a stand structure and species composition that minimizes serious risk of damage caused by mammals...and will allow treatment..."*

- On page 4-55, the Standards and Guidelines under Insects and Disease (Pests) states, *"Use Integrated Pest Management (IPM) strategies for early detection, suppression, and prevention of Forest pests and to manage pests within the constraints of laws and regulations...Strategy selection will be based on environmental analysis...Cooperate with the Animal and Plant Health Inspection Service (APHIS) in accord with the Memorandum of Understanding between APHIS and the USDA Forest Service."*

- On page 4-49, a Timber Planning Assumption for Management Area 1 states, *"Rodent control will be needed on 50 percent of the planted acres. This will normally be accomplished through trapping or poisoning."*

- On page 4-61, Direction for Management Area 3 states, *"Timber management will be similar to that of Management Area 1 but constrained to meet wildlife objectives."*

The preceeding statements from the Forest Plan provide the strategic objectives for animal damage control on the Wallowa-Whitman National Forest. I assume that in making these statements, the Forest Supervisor concedes the fact that the timber harvesting practices on some portions of the Forest will necessitate the expenditure of funds to control pocket gophers.

Population Indices

Before evaluating gopher control practices, land managers need a fairly reliable estimation of the gopher population. Reid (1973) states, *"A single trap-out on an area basis is probably the most accurate and has the most utility..., however, care should be taken that the area trapped is large enough."* Because of the gophers' fossorial habits and solitary nature, a single trap-out provides neither a quick nor economical method for large areas. Some gophers avoid both the live and kill traps, and therefore, never get counted. Trapping along predetermined transects and banding and/or toe clipping the captured gophers can yield excellent information on population and survival, but that process is time consuming and expensive.

A population index, that is, an indirect estimate of a population based on indicators of the animal's presence, provides a reasonably accurate estimate, neither too difficult to obtain, nor too expensive, nor impractical on the thousands of acres treated annually. Regardless of the method of estimation used, the time of sampling as it relates to the annual population cycle will influence the results. Because the young-of-the-year have already dispersed and the rate of mound building is greatest, late summer and fall is the best time to obtain population estimates. When comparing gopher populations over time, one must sample a population during the same relative period in the population cycle each year to avoid significant differences.

The alleviation of damage forms the basis of a control program. Land managers should not measure control in acres, or in number of animals eliminated, but by the degree that the deleterious effects of a particular target population have been diminished to the point that the land managers no longer consider control necessary (see pages 25-26).

Measuring the effectiveness of a gopher control program by the number of acres treated encourages a quick, less intensive treatment, and produces a less conclusive figure. In most cases, a reliable and adequate population index limits the objective of control to the gopher's impact on seedling damage. Biologists believe that reductions of greater than 70 percent of a pocket gopher population index must occur to achieve any significant reduction of gopher damage to plantations (Forest Service Handbook 1988). Since on-the-ground conditions vary so much, individual land managers cannot predetermine a minimum population index number before initiating gopher control. They must make those decisions based on the available gopher survey data and local experience.

Three types of pocket gopher surveys used to establish a population index are:

1. Reconnaissance: This simply determines the presence of pocket gophers, the extent of damage potential, and the relative density of pocket gopher activity. The evaluator looks for recently created mounds and winter casts, and estimates a rough percentage of a particular area that has an active population associated with it.

2. Mound-Count Surveys: These are easy to do and are generally conducted to approximate population density. Using a plot survey that samples 1 to 5 percent of the area provides a basis to ascertain the locations of concentrated gopher activity, an approximation of numbers of gophers per acre, and the range of activity over the entire area. The Forest Service Handbook (1988) does not recommend control measures if less than 25 to 35 percent of the plots in less than 2-year old plantations contain active gopher mounds, and 40 to 50 percent in the 3- to 5-year old plantations. Tempered by the evaluator's judgment based on local experience, the percent area affected, and the average number of mounds per acre, the mound count survey provides a reasonable basis for determining the need for control measures.

A mound-count survey, by itself, should not provide the sole decision determinant on whether to implement a control program. The impact of pocket gophers will vary according to tree size, available habitat and various other environmental factors. Therefore, one must also evaluate the damage to a plantation that is actually attributable to gophers in order to substantiate that it is sufficient to warrant control.

Because the extent of area affected and the number of recent mounds indicate the relative feeding pressure of pocket gophers, sign counts–easily inventoried and strongly correlated with seedling damage (Anthony and Barnes 1978)–provide a reasonable indication of future potential damage.

Because earth plugs do not affect the reliability of only counting mounds, they can be ignored in any tally of gopher sign. Again, late summer or fall is the best time to obtain these figures.

Population indices based on mound counts have more reliability than those based on winter soil casts alone, although the latter do give an indication of the overwintering activity. Reid (1973) reports that casts may have utility for estimating the relative abundance of ***T. talpoides*** in early summer, which occurs before the young disperse. However, Teipner et al. (1983) state that population estimates based on soil cast indices produce erroneous results, because wintertime activity depends on the initial population going into winter, the overwintering survival, length of snow cover, and whether the soil froze beneath the snowpack.

3. Open-Burrow Surveys: These are generally conducted prior to treatment and 1 to 2 weeks after treatment to evaluate the effectiveness of the control measures. Because of two behavioral traits of gophers–their solitary nature and their tendency to plug any hole in their burrow system–the open-burrow method gives a more accurate index of population than does the mound-count method. To obtain this figure, you expose a main runway in a representative sample of the burrow systems in a unit, and check the holes within 48 hours to see if the gophers closed them. If a hole remains open, the burrow system is assumed to be unoccupied. Hungerford (1976) predicates this index on the fact that if the humidity at ground level is less than 94 percent, a gopher would instinctively close all exposed holes in its burrow system.

Notwithstanding, Evans (1987) states, *"Even the open-hole technique can give erroneous results. There are a number of cases documented with radio-telemetry where burrows appeared open but in reality were plugged several feet back from openings. Hence, an open hole assessment would have indicated 'dead gopher' where in reality a live gopher existed."* Tickes (1983) states, *"A correlation coefficient of .48 indicated that one or both of these indices [mound-count and open hole] was a poor measure of activity,"* but in the next paragraph states, *"The open hole technique was felt to be a more direct and accurate indication of control and was used in our evaluations"* (see pages 8-10).

Efficacy

To gauge how a method of control actually performs, scientists use the term "efficacy," which means the capacity of that control measure to produce the desired effect, i.e., the reduction of the gopher activity or population. Evans (1987) states that radio-telemetry studies have demonstrated that a *"reduction in activity is not directly proportional to numbers of gophers killed or trees saved."* A multitude of factors affect efficacy (Crouch and Frank 1979), some dealing with the bait itself, some with the bait formulation, some with the animal, some with baiting, some with habitat, and some with the environment. A few of the most obvious reasons for poor control deal with: sublethal amounts of strychnine on the bait at time of consumption; low palatability of the bait or bait carrier; bait aversion; tolerance to strychnine; ability to regulate intake of strychnine at sublethal levels; not getting the bait to gophers; first-time versus second-time baiting; time of year (spring versus fall); population levels; reinvasion; crew inexperience; lack of incentive; poor soil moisture; and on and on *ad infinitum.*

In all direct or indirect suppression activities, the objective of pocket gopher control should alleviate or prevent resource damage. Our inability to predict the future with absolute certainty forces us to recognize and treat existing animal damage problems before they become severe enough to cause extensive damage. These tactical decisions involve more narrowly-defined objectives than those stated in a Forest Plan, and we subject them to reasonable restraints. However, land managers must hinge their decision to control animal populations based on their analysis of the extent of damage happening or expected to happen, in relation to other resource needs or expected adverse effects. Land managers must also accept some minimum amount of resource damage by gophers, whether it be seedlings eaten or soil disturbed, or the possibility of minor amounts of secondary effects. Research in the field of animal damage management may produce improved and more reliable methods and/or chemicals in the future, but the information presented below represents the best information available at this time.

Scientists have arbitrarily established field efficacy for pocket gopher control at 90 percent, i.e., a 90 percent reduction of the population index used. But Evans (1987) claims *"favorable reduction of tree mortality has occurred when efficacy has been assessed at 60 percent or less by the open-hole technique."* Since the annual natural mortality of pocket gophers averages around 70 percent, most of which occurs before autumn, any treatment prior to autumn with an efficacy of less than 70 percent probably means wasted efforts, or at least a less efficient means to protect existing seedlings. However, a 70-percent control in the fall can prevent considerable damage during the winter and spring months before green vegetation reappears.

Marsh and Steele (1992) explain how the percentage of the gopher population killed sometimes provides a misleading measure of control, because it does not take into account the ***number*** of surviving gophers. They believe that to achieve acceptable long-term control effects, the population must decline to less than 2 pocket gophers per acre (5 per hectare). For example, a 90- percent control of 10 gophers per acre (25 per hectare) allows the survival of 1 gopher per acre (2.5 per hectare), below Marsh and Steele's suggested limit of 2. However, a 90 percent control of 25 gophers per acre (62 per hectare) allows the survival of 2.5 gophers per acre (6.2 per hectare), above the critical figure of 2, thus leaving sufficient gophers to repopulate the area rapidly. Allen et al. (post 1977) find that *"regardless of the original population density [of* **T. talpoides** *on harvested units on the Targhee National Forest],"* they reduced each treated population to 1.6 gophers per acre (4.6 per hectare) or less. The above examples demonstrate that controlling a low population can prevent a more serious buildup in the future.

When contemplating gopher control measures, land managers must realize that *"complete control may upset the integrity of ecosystems in a manner that we cannot possibly predict from our current knowledge of the structure and function of those systems"* (Case 1983). Therefore, my recommended approach does not attempt to exterminate gophers, but merely to reduce their damage to tolerable levels. Scheffer (1910) stated 84 years ago what we certainly realize today, *"We cannot hope to exterminate the animal [pocket gopher], for the conditions under which he lives are such as to render extermination practically impossible,"* and we wouldn't want to consider it anyway.

To anticipate and control pocket gophers in problem areas requires an understanding of the gophers' biology, habits, and responses to changes in their environment, especially to their forage and cover. However, as with all control methods, reinvasion remains a possibility. Survivors, their progeny, and invaders from adjacent areas can quickly repopulate a treated area, thereby making it necessary to utilize a combination of different control methods. *"No single control method is considered completely effective under all conditions, because the same species may respond differently to changes in habitat or other conditions"* (Forest Service Handbook 1978).

From a biological point of view, the most effective time to bait is in the spring before mating, or before the young-of-the- year are born, weaned or dispersed. But in northeast Oregon, this time presents many contract scheduling complications and access problems due to snow cover differences on many scattered units, and tree planting contracts going on concurrently. Therefore, land managers should concentrate gopher baiting efforts in the fall, thus reducing the population levels before winter, when most gopher damage to conifers occurs. Barnes (1974) finds that, *"over 90 percent of all tree damage occurred during winter, and virtually all injured trees died."*

Midsummer baiting is the least effective, because the decrease in soil moisture and increase in soil temperature cause the gophers to spend more time at lower depths. There is also less surface activity to observe in midsummer because gophers push excavated soil into unused tunnels rather than moving it to the surface.

"Successful damage control requires organizational commitment, persistence, and the timely coordination of all regeneration practices" (Teipner et al. 1983). When planning gopher control in forest plantations, land managers must consider the size, density, and distribution of the seedlings, the relative abundance of the gophers, the possible effects on nontarget species, and other variables such as:

- The physical restraints caused by the site, i.e., soil type, topography and size of the unit.
- Availability of preferred gopher forage.
- Budget and personnel to administer the program.
- Ecological and political considerations.

Some factors to consider that make damage control difficult include:

- Soils are too dry or too wet during baiting.
- ***All*** burrow systems in the treatment area must be baited.
- Efficacy must exceed natural mortality, which averages about 70 to 75 percent per year (Capp 1976).
- Survivors of gopher control efforts have the capacity to reproduce and reoccupy treated areas. Also, if reinvasion from the surrounding areas constitutes the biggest threat, the smaller the area treated with control measures, the faster the gopher population will recover. Conversely, the larger the treated area, the slower the population will recover.
- Treated areas may need periodic retreatments.

In any case, Marsh and Steele (1992) recommend baiting a 400-foot (122-meter) buffer zone around each treated unit to slow the reinvasion rate (see pages 29-38).

Placing bait in burrow.

Once land managers initiate gopher control, they must continue it until the habitat changes sufficiently that gopher damage becomes inconsequential to the crop trees. Land managers cannot hope to regulate one component of the ecosystem, e.g., the gopher population, without affecting the other components. After reducing the local gopher population, either the gophers' natural enemies will keep the population in check (see page 29), or the habitat changes such that the treated area no longer has the vegetative capacity to support the previous population of gophers, i.e., a change in the vegetative component of the ecosystem.

The availability of unoccupied burrow systems increases the survival rate of dispersing juveniles. If the habitat can still support gophers, offspring from survivors and those that immigrate from the surrounding area will quickly repopulate the treated area. Therefore, reducing the gopher population actually stimulates juvenile survival by creating vacancies in the already established burrow systems. But since we base treatments on the long run, this is only a temporary phenomenon.

Lethal Methods of Control

"Vertebrate species attain pest status when they have detrimental economic or aesthetic impact on human activities. We seek to economically reduce that impact by exclusion and control" (O'Brien 1986). And because gopher habitats and environmental conditions vary so much, *"It is unlikely that a single [control] technique will be developed that can be applied to all damage situations"* (Barnes 1976).

Introduction of Diseases and Parasites

Rodent populations cycle naturally, and often face severe reductions because of the rapid transmittal of diseases. However, because pocket gophers lead a solitary lifestyle almost entirely underground, the transmission of diseases becomes a slow and difficult process, reducing its effectiveness as a method of control.

Pocket gophers already host numerous internal and external parasites, but none appear life threatening, have more than a minor effect on gopher population levels, or pose a public health problem to humans (Teipner et al. 1983). Any increase in these parasites would probably have a negligible effect on the gopher population.

Internal parasites include roundworms ***(Nematoda)***, tapeworms ***(Cestoda)***, warbles ***(Cuterebra)***, and some protozoans. A liver parasite ***(Capillaria hepatica)***–common in high population densities–can cause atrophy of the liver. External parasites include fleas ***(Capillaria)***, lice and mites ***(Mallophaga)***, and ticks ***(Acarina)***. The latter, however, can be vectors for Rocky Mountain Spotted Fever. The gophers' solitary life style in subterranean environments, their grooming behavior, and molting characteristics severely limit the transfer of ectoparasites.

Fumigation

Marsh (1992) states that fumigants *"are too expensive and lack a sufficiently high degree of efficacy for use in production agriculture or forestry."* Stewart and Baumgartner (1973) state that *"Poisonous gasses have not proven to be consistently effective in controlling pocket gophers."* Although this method poses little risk to non-target animals when applied to active gopher burrow systems, it is time consuming and has been effective only for low density populations (Godfrey 1988), therefore, control over large areas would become cost prohibitive. Even though *"toxic gasses have been used for vertebrate pest control for many years, there is relatively little efficacy data from controlled experiments"* (Moline and Demarais 1988). Gophers can quickly plug a tunnel into which toxic gas has been placed (Washburn and Michel 1925), and retreat to a protected part of the burrow system, thus surviving the treatment.

Gas cartridges and gas bombs have a limited use in high value areas where other means cannot be used; however, they are costly and generally ineffective in large scale operations. Plesse (1984) reports that he had good gopher control on a golf course by using gas cartridges followed by a carbon monoxide treatment from his tiller. On such a small scale project he achieved good control, had no hazardous residues, did no damage to the existing vegetation, did not affect the golfers, and did not observe any apparent secondary effects.

Fumigation is neither economical nor effective in sandy or dry soils. The soil must be very moist in order to concentrate the gas in the tunnels and minimize diffusion through the soil itself. However, gophers frequent sandy soils more than clay soils, because the latter have poor gas diffusion properties. Since soil conditions vary widely and soil moisture changes constantly, the timing of fumigation with the ideal conditions for good penetration or concentration of toxic gasses becomes quite difficult.

Placing calcium cyanide in burrows, which produces hydrocyanic acid gas and hydrated lime when it comes in contact with moisture, has had poor success (Washburn and Mickel 1925), and is no longer considered a viable treatment. The highly poisonous gas works well in clay, but poorly in sandy soil. Also, since this method requires a lot of calcium cyanide–as compared to poisoned bait–for the treatment of a given area, land managers would have to purchase, handle, and transport a greater volume of hazardous material.

The use of aluminum phosphide, registered for burrowing rodents (Marsh and Steele 1992), has worked well as a pocket gopher fumigant, especially at elevated soil moisture levels in landscaped areas and in agricultural areas. Marsh (1988) states that ***T. bottae*** do not detect phosphine gas before they inhale a lethal dose. Marsh (1993 personal communication) believes that *Phostoxin®* may have a place in forestry, its costs ranging somewhat more than a strychnine treatment, but less than trapping. Littrell (1990) finds aluminum phosphide hazardous to snakes and owls, and even though he has *"no documentation of adverse effects,"* suggests that applicators check burrows for signs of snakes and owls prior to using it.

Conrad and Laughlin (1971) tried the introduction of anhydrous ammonia (NH_3) into the burrow system, but it gave poor success (46 percent kill). DeCalesta and Asman (1987) mention the burning of dusting sulfur with a propane weed burner in the gopher burrows, but make no mention of its success

Sullins and Sullivan (1992) used a *Rodentorch®*, which explodes a mixture of propane and oxygen after injecting it into the burrow, the concussion supposedly killing the rodents. They found this system less efficacious on black-tailed prairie dogs and Richardson ground squirrels than the initial trials on northern pocket gophers in Nevada, and less effective than their concurrent trials with an EPA-registered gas cartridge and aluminum

phosphide fumigants. Sullins and Sullivan (1993) used the same device on the northern pocket gopher with population reductions of less than 12 percent. They speculate that a more intensive treatment might have increased efficacy, but the increased labor and other costs would have risen to a point where the field implementation would far outweigh productivity. Combining *Rodentorch®* with gas cartridges and aluminum phosphide fumigants increases the control costs to levels *"prohibitive on anything but very small applications."*

Toxic Grooming Agents

Although toxic foam proved efficacious against mountain beaver ***(Aplodontia rufa)*** (Martin 1969 and Oita 1969), the habits of pocket gophers differ sufficiently to preclude its effectiveness against them. Barnes (1973) mentions the possibility of using chemicals such as wetting or tacky substances that, when placed in burrows, would interfere with gophers' grooming and conditioning of their hair, hopefully causing them to migrate to another area. As with fumigants, gophers can quickly plug a tunnel after the placement of any toxic substances that can contact their pelage, and retreat to a protected part of the burrow system. Although not intended as a toxic grooming agent, Barnes (1982) finds that some gophers ingested a fatal dose of zinc phosphide during grooming.

Although researchers have not studied toxic grooming agents for pocket gopher control very much, they may have future merit (Marsh, Rex E., 1993 personal communication.)

Trapping

This method was thought to provide a suitable and effective substitute for poisoning in relatively isolated areas, but it takes more time, money and labor to implement. Crouch (1982) believes it logistically unsuitable on a large scale, but practical on: small areas; high value situations, such as around buildings or dams; and as a supplement or follow-up to other methods of control. However, more recent experiences have demonstrated that it does provide adequate control over large areas. The Pine Ranger District on the Wallowa-Whitman National Forest accomplished 500 acres (202 hectares) in 1992 at a cost of approximately double what a strychnine treatment would have cost, but the trapping had no post-treatment monitoring required as would the strychnine treatment. Some Ranger Districts have also used kill trapping to avoid the use of poisoned bait in areas with spotted owl populations (Witmer, Gary W. 1994, personal communication).


Pouring bait into probe hole.

Marsh and Steele (1992) state that pocket gopher trapping on large areas can have a reasonable cost effectiveness if it begins before the population reaches about five animals per acre (12 per hectare). Crouch and Frank (1977) find two successive trappings, 2 to 4 weeks apart, more effective than one treatment.

Smeltz (1992), in what was probably the first large-scale (974-acre) pocket gopher trapping contract on National Forest lands in the Pacific Northwest Region, finds that three different contractors achieved similar results. Each trapped their assigned acres twice as per the contract. Contractor A averaged 11 traps per acre (27 per hectare), achieving four gopher kills per acre, and about 0.2 gophers per trap set. Contractor B set nine to 19 traps per acre (22 to 47 per hectare), achieving 3.9 kills per acre and about 0.14 gopher kills per trap set. Contractor C set six to10 traps per acre (15 to 25 per hectare), achieving 3.5 gopher kills per acre and about 0.2 gopher kills per trap set. Even though the contractors trapped a total of 40 nontarget animals–21 ground squirrels ***(Spermophilus spp.)***, 17 chipmunks ***(Eutanius spp.)***, and two long-tailed weasels ***(Mustela frenata)***–Smeltz considered the 0.04 nontarget animals per acre (0.1 per hectare) *"an insignificant amount."* Trapping costs averaged about twice what strychnine baiting would have cost.

Most literature sources tend to recommend the *Macabee®* trap. Its popularity is probably based on its ease of installation and its trapping success.

Hole dug; box trap and carrot bait ready.

Encouragement of Predators

Natural predation alone cannot control a gopher population in a specific area, but it does complement and work most efficiently when combined with other control methods. Marsh and Steele (1992) state *"The control of pest species with predation is a concept fraught with misconceptions about predator-prey relations. These species evolved together; the number of prey available generally controls the number of predators in the area rather than the predators controlling the prey...Predators may regulate the population of a prey species in local situations but rarely to levels below economic damage thresholds."*

Vertebrate predators include, but are not limited to: great horned owl ***(Bubo virginianus)***, red-tailed hawk ***(Buteo jamaicensis)***, Ferruginous hawk ***(Buteo regalis)***, Swainson's hawk ***(B. swainsoni)***, common barn owl ***(Tyto alba)***, great grey owl ***(Strix nebulosa)***, long-eared owl ***(Asio otus)***, burrowing owl ***(Speotyto cunicularia)***, northern goshawk ***(Accipter gentilis)***, American kestrel ***(Falco sparvenius)***, weasel ***(Mustela spp.)***, coyote ***(Canis latrans)***, bobcat ***(Lynx rufus)***, badger ***(Taxidea taxus)***, skunk ***(Mephitis spp.)***, bullsnake ***(Pituophis sagi)***, gopher snake ***(P. melanoleucus)***, and rattlesnake ***(Crotalus spp.)***.

Fitzner et al. (1977) report that northern pocket gophers provided 19 to 37 percent of the prey items in his study of Ferruginous hawks in eastern Washington. In his central Washington study, Fielder (1982) reports that northern pocket gophers provided 48 percent of the biomass consumed by barn owls, but less than 6 percent of the total biomass in the long-eared owl and great horned owl diets. In contrast, Bull, Wright and Henjum (1989) report that, based on the 1,128 pellets they collected within 150 meters of occupied long-eared owl nests in 1 year near Starkey, Oregon, adult gophers accounted for 40 percent of the total biomass consumed, and juvenile gophers accounted for 34 percent, for a total of 74 percent of the owls' diet.

Bull and Akenson (1985) find that common barn owls in their northeast Oregon Grande Ronde Valley study fed heavily on pocket gophers from April through June, with pocket gopher parts in 23 to 53 percent of the fecal pellets collected. These data agree with Bull, Wright and Henjum (1989), who find sub-adults traveling on the ground after they leave their maternal burrow system from March through May very susceptible to avian predators, especially owls. Based on a 4-year collection of 1,923 pellets, also in the Grande Ronde Valley, Bull, Henjum and Rohweder (1989) find that 67 percent of the prey biomass in their great grey owl study consisted of pocket gophers.

Howard et al. (1985a) find that artificial raptor perches do not significantly affect gopher populations, although they probably aid in preventing a population buildup by limiting aboveground dispersal. They also add that raptors are not known to eliminate their food supply through predation. Leaving 1 or 2 snags per acre (2 to 5 per hectare) does provide perches for natural gopher predators such as hawks and owls. Reid (1973) cites a case where 1 year after placing an artificial roost in an area with gopher mounds, gopher sign disappeared within a 37-foot (11-meter) radius of the roost.

Toxic Baiting

The most common *"practical and efficient method of controlling large numbers of gophers is to put out toxic bait by hand or machine"* (Marsh and Howard 1978). *"The perfect chemical is one which will eliminate, repel, or change the habits of the animal for which it was intended without endangering man, other animals, or the environment. A good rodenticide is toxic enough to kill pests with small amounts and it should be acceptable to the pest so it will be taken in lethal portions"* (Baumgartner 1980). Rodenticides are generally classified as acute (single feeding) or anticoagulant (multiple feeding) toxicants.

Because of the rapid onset of symptoms, acute toxicants can cause bait shyness when the target animals do not ingest a lethal dose. Other problems include inconsistent successes in the field, and scrutiny by the environmental community and in-service people concerned about pesticide hazards. Disadvantages of underground-placed bait include the possibility of getting covered up and mixed with soil in the burrow during the gophers' normal tunnel maintenance, and sprouting, caking, and molding after absorbing moisture in the burrow, the latter tending to reduce palatability. Wang et al. (1986) finds that under laboratory conditions, ***T. mazama*** preferred fresh bait, while ***T. bottae*** actually preferred moldy bait to fresh bait. Though these researchers did not speculate on why this difference occurred, I believe that since moldy bait has less toxicant than fresh bait, the ***T. bottae*** simply capitalized on this difference (see pages 32-34).

The Forest Service can only use pesticides registered or otherwise permitted in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended, which authorizes the registration, labeling, distribution, sale, shipment, receipt and use of pesticides. The application of rodenticides on National Forest lands also falls under the provisions of the NEPA, and the implementing regulations of the Council of Environmental Quality (CEQ). As stated in FSM 2150, in order to manage, coordinate, and ensure the proper use of any rodenticide, the following must be adhered to:

- ❑ *The recommendation to use, and the actual use of, a rondenticide will be based on an analysis of its effectiveness, specificity, environmental impacts, and economic efficiency.*
- ❑ *Proposed rodenticide projects will be coordinated with appropriate State fish and wildlife agencies.*
- ❑ *Forest Service employees will conduct a Biological Evaluation if T&E species are present, and initiate a Section 7 consultation with the USDI Fish and Wildlife Service when there is a judgment of "may effect."*
- ❑ *The use of rodenticides in designated wilderness will only take place when determined necessary to prevent significant losses to resource values on public or private lands bordering the wilderness. Only the Regional Forester has the authority to approve this.*
- ❑ *Applicators will ensure the safe, judicious, and effective application of any rodenticide.*
- ❑ *Forest Service employees and/or contractors will transport, store, and dispose of rodenticides and their containers in accordance with applicable Federal, State, and local laws and regulations.*
- ❑ *Monitor any sensitive environments mentioned in the EA during the application of the rodenticide in order to detect and evaluate unanticipated effects.*
- ❑ *Forest Service employees will establish adequate controls to ensure that the application of rodenticides is restricted to the intended target areas and does not result in unacceptable non target effects.*
- ❑ *Forest Service employees will conduct posttreatment evaluations for all rodenticide projects.*

The first use of anticoagulants for gopher control began in the early 1960's, even though pocket gophers had somewhat less susceptibility than commensal rodents (Marsh 1987a). For first generation anticoagulants to have effective control percents, gophers must consume large quantities of these baits over several days. Scientists have conducted little research on the highly toxic–therefore, lower doses cause mortality–second generation anticoagulants (Marsh 1987a). Having higher concentrations of the active ingredient (such as bromadiolone), gophers receive a fatal dose in one day's feeding, or at most, in a few days.

Probing for a gopher burrow.

Researchers have expressed a need for safer, i.e., less toxic baits, and those that have low secondary hazards. Baits that have been tested, but not yet approved for field use, include winter-applied baits in plastic bags, bait in cardboard and plastic tubes, long-lived baits, and those with hyperdoses of vitamin D_3, such as *Quintox®* (Bonar 1990), presently registered for commensal rodents only. Bell Laboratories, Inc., however, is pursuing EPA registration of *Quintox®* for the control of burrowing rodents.

Ray (1978) finds *"no significant differences in activity levels or tree damage between the standard and bagged-bait treatments."* Lee (1986) finds that baits sealed in plastic bags *"remained toxic and acceptable in burrow systems longer than paraffin baits...[and] favored in the laboratory tests; however, in the field tests, bag baits were sometimes pushed out of the tunnels unopened, whereas paraffin baits were rarely pushed above ground."*

Paraffin-coated baits look promising for multiple deaths with only one bait application. Tunberg et al. (1984) define two behavioral traits possessed by gophers which allow multiple deaths from one baiting: gophers will invade any unoccupied burrow system

(sealing off the previously poisoned occupant in a dump or tunnel with feces, old nest material or other debris if necessary); and the invading gopher will utilize the food caches of the previous occupant. Marsh (1987a) shows that *"experimentally,"* up to four gophers can die from a single baiting.

Since paraffin-coated baits degrade more slowly, previously-cached bait blocks remain readily available for reinvading gophers to utilize. Baits with various grain mixes formed into paraffin blocks have had field efficacy trials. Somewhat protected from intraburrow moisture, they remain palatable for a longer period of time before molding, and *"bioassays of poisoned animals show that 95-98% of the active ingredient [diphacinone] in the bait is degraded. Tests show that birds fed exclusively with poisoned voles have exhibited no signs of illness in reference to the possibility of secondary poisoning"* (Mitchell 1988) (see page 35).

Although this concept appears sound, none of the tested baits has proven to be the ultimate gopher bait. Due to the slow acting nature of these first generation anticoagulants, gophers eat much more of the bait than they need to, leaving less for the succeeding gophers that occupy the burrow (Tunberg et al. 1984). Therefore, in an effort to slow down the feeding on these baits, researchers have added nonfood items to the bait blocks, but haven't yet determined the ideal mix where the gophers ingest sufficient toxin before tiring of the bait and leaving it alone. One advantage of bait impregnated with hyper-doses of vitamin D_3 is that once the animal ingests a lethal dose, all *"feeding on the bait or any other food usually stops, or very nearly stops"* (Marsh and Tunberg 1986).

Wang et al. (1986) find that pocket gophers show no shyness toward paraffin baits, preferring 30 to 60 percent wax, depending on the bait grain used; readily eat bait cached by other gophers, even if moldy; and prefer a salt content in bait from 0.2 to 0.6 percent, shying away from bait that contains greater than 0.6 percent. Evans, Campbell and Engeman (1990) find salt unimportant as an additive to strychnine formulations and do not recommend its use.

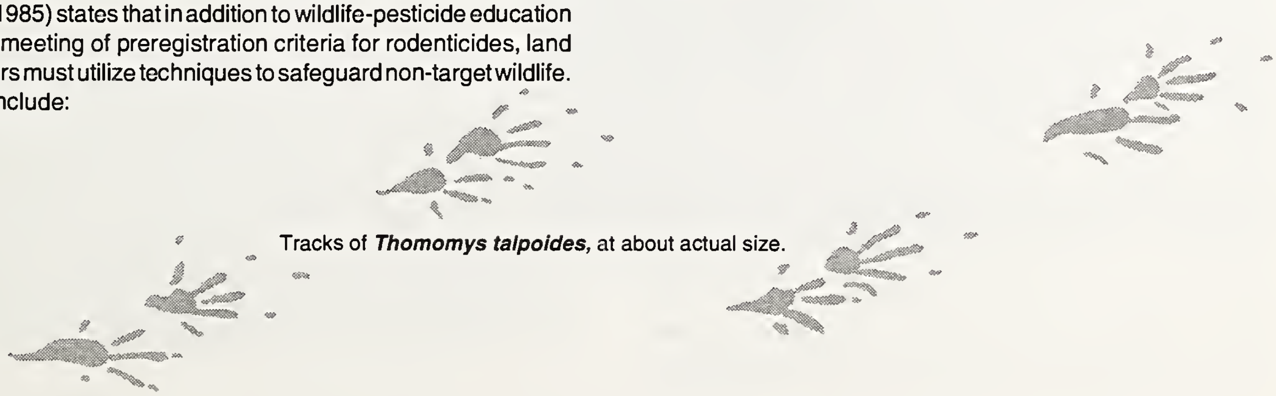
Marsh (1985) states that in addition to wildlife-pesticide education and the meeting of preregistration criteria for rodenticides, land managers must utilize techniques to safeguard non-target wildlife. These include:

Appropriate Selection of Rodenticides and Bait Composition: Rodenticide selection affects other factors such as bait concentration, method, and timing of application. In choosing an appropriate rodenticide, select one for which the target rodent has a high susceptibility and the potential nontarget species have low susceptibilities.

Effective rodent baits must compete successfully with available natural foods. Grain baits are readily available, store well, have reasonable prices, and rodents generally accept them. Since seed-eating birds more readily accept wheat and milo, strychnine-treated oats provide a lesser chance for nontarget poisoning. Although rolled grain deteriorates more quickly in a wet or moist environment (Marsh 1985), the process of flattening kernels by rolling or crimping alters their normal appearance, thus making them appear larger and less like food items to grain-eating nontarget species. When dyed, the bait kernels also become less attractive to birds, because they often select food based on color.

Since rodents rely on odor for selecting foods, and lack true color vision–they perceive colors as shades of black and white–bait pigmented with bright green or yellow work well. And if the dye used has no odor or taste, it does not influence bait consumption. Since birds perceive and utilize color in selecting food items, they tend to reject gray- and black-colored baits more readily. Color also aids humans in distinguishing toxic bait from food or animal feed.

Perishable baits such as carrots or cabbage cost more and have other hazards in preparation and handling, but because of their high efficacy, require fewer bait sets, thus reducing the amount of rodenticide placed in the environment. Perishable baits deteriorate more rapidly than grain baits, and even though seed-eating birds avoid them, other small mammals relish them. However, Marsh (1992) states, *"From an efficacy point of view, carrots were considered the best fresh fruit or vegetable baits [but] since technical or high concentrates of strychnine are no longer registered for use by growers, the use of carrots as perishable baits is no longer an option."*



Tracks of ***Thomomys talpoides,*** at about actual size.

The use of emetics (an agent that induces vomiting) works well for rodents because rodents cannot vomit. If a nontarget animal capable of vomiting ingests the bait, it can expel all or most of the chemical. Although, none of the EPA-approved gophercides contain emetics, zinc phosphide has emetic properties (see pages 42-43).

Application Rate and Timing: The rate of application refers to the amount of bait per placement or per acre, generally in direct proportion to the population density. Depending on the biology and behavior of the target species, the most efficacious application rate follows the instructions on the label, and affects the target species with a greater probability than nontarget species. The method of placing gopher baits underground in active pocket gopher burrows, with each set containing the label-indicated amount, presents the fewest hazards to nontarget species.

Land managers must choose the baiting seasons to assure the maximum acceptance of the bait by the target species with a minimum amount of residual bait left in the environment, and/or a time when possible nontarget species will less likely be affected by the bait or by possible secondary consumption of the treated target species. Timing also includes the control of target populations before they reach elevated levels that require larger amounts of toxic bait placed in the environment.

Adequate gopher control depends on low survival percents within the treated area and the proximity of other gopher-occupied areas. Since all control methods have problems with reinvasion, one can achieve a significant reduction of the gopher population and allow less damage to seedlings with two successive treatments (2 weeks apart) instead of a single treatment (Crouch and Frank 1979).

The factors that affect longlasting gopher control include season of baiting, number of gophers that survive the baiting, and the adequacy of the treated buffer zone. The latter two account for the apparent ineffectiveness of some baiting programs. However, associated with season of baiting, Cheney and Vander Wall (1985) find in their study of how strychnine-killed rodents affect raptors, that because *"cold temperatures have a potentiating effect on strychnine, a given dose of strychnine ingested in winter or early spring will have a greater effect on [raptor] behavior than the same dose ingested in the summer."* These data may or may not have relevance for the ingestion of strychnine by pocket gophers.

Evans, Campbell and Engeman (1990) find, *"In our study, spring/summer gopher populations were quite high and young-of-the-year were continuously moving into new territories. This shuffle resulted in a 6-10% reoccupancy rate of sample plots. However, sufficient amounts of cached bait, presumably maintained in a dry condition in nests and food caches, seemed to offset the reoccupancy problem. The end result was a continuous die-off of gophers over a 51-day observation period,"* that is, well into the hot summer months. They also state that *"gopher activity readings taken too soon after baiting may yield low kill results. The problem is accentuated if reinvasion...is occurring. Readings taken 30 to 35 days after baiting instead of the 7- to 14-day waiting period currently used by most forest managers may yield a more accurate assessment of a gopher control program."* Notice the use of "may." Other researchers insist on the 7- to 14-day period.

Toxicant Concentration: Toxicologists normally design baits to contain an optimum amount of the poison that will provide a fatal dose to the target rodent based on the susceptibility of the animal, the average weight, and the amount of food consumed in a single feeding for acute rodenticides, or amount of food consumed daily for slow-acting anticoagulants (Marsh 1985). Too little toxicant has poor efficacy because the target animals do not ingest enough for lethal results. Too much toxicant may cause the target species to reject the bait, which may result in a hazard to nontarget species or to the immediate environment.

Taste does not appear as a critical factor in a gopher's choice of food, and despite the very bitterness of strychnine, it seems not to bother gophers, who after recovering from a sublethal dose, will return to the same bait (Willis 1981). Howard et al. (1968) find that they *"were unable to train a single individual* **[T. bottae]** *to shy from wheat containing strychnine alkaloid."* Even though the gophers suffered repeated severe convulsions that lasted about one-half hour each, they consumed strychnine-treated wheat until each of them died. Howard et al. (1985b) find similar results.

Willis (1981) finds that 0.1 percent strychnine bait too weak for effective control, and the 1.0 percent very effective, as does Howard et al. (1958b), but because of the dustiness of the latter formulation, the applicators face more dangers in handling it. The 0.5 percent formulation on oats also works well, and the EPA label recommends it for pocket gopher control projects. Since bait concentration closely correlates to rate of application and the distribution of the bait, an adjustment of one of those factors frequently requires a counterbalance in one or more of the others. A highly efficacious rodenticide means less toxicant applied less often to the environment, and a higher probability of safeguarding nontarget wildlife.

Bait durability depends on the moisture and temperature conditions within the burrow. Baits retain their toxicity if they remain dry. Strychnine bait produces the best results if ingested within 2 weeks of placement, but after 3 or 4 weeks (if not buried during normal tunnel maintenance), it loses potency and toxicity. Whole grain baits germinate, and other baits mold more slowly in the spring and fall than in the summer. Also, gophers may not find bait placed in tunnels near the surface during the summer because they frequent their deeper burrows in order to escape the heat and dryness of the upper soil layers (see pages 8-10).

The EPA has registered four chemicals for the control of pocket gophers: strychnine, zinc phosphide, diphacinone, and chlorophacinone (Askham 1988b). The latter two are first-generation anticoagulants, which Marsh (1992) states *"provide the best alternative to strychnine"* in areas where the use of strychnine may be considered inappropriate, such as populated areas. None of *"the second-generation anticoagulants [e.g. brodifacoum and bromadiolone], which are generally more toxic to rodents and may be fatal in a single day's feeding, or at most a very few days, have characteristics that theoretically make them much more attractive as potential gopher control materials"* (Marsh 1987a).

Strychnine: This is a highly poisonous compound derived from the seeds of ***Strychnos nux vomica,*** a plant that grows in southern Asia. It has a very bitter taste, remains stable as a powder, is not readily absorbed through normal skin contact, and is not water soluble. But once ingested, absorption occurs quickly in the intestinal tract. Because it causes increased reflex excitability of the spinal cord, normally minor stimuli produce seizures and exaggerated tetany, i.e., muscular spasms. The simultaneous contraction of all muscles produces secondary responses such as pain, increased metabolism, temperature disturbances, and increases in blood pressure and heart rate. Death results from asphyxia, that is, being unable to breathe (Forest Service Handbook 1978). Marsh (1992) states that, *"strychnine remains the most economical and efficacious of the rodenticides available for use in production agriculture and forestry."*

A fast-acting convulsive poison, it causes mortality in a short period of time after ingestion of a lethal dose. Since the fur-like lining in the cheek pouches of pocket gophers does not readily absorb the strychnine alkaloid formulation, the gopher must swallow the toxic bait. Though most researchers find strychnine to cause 70 to 100 percent control, Tickes (1983) only achieved a range of 5 to 25 percent control with eight different formulations. He attributed much of his poor success to the availability of alternative local food (alfalfa) in his study area.

In most cases, the initial indications of strychnine poisoning occur within 10 minutes of ingestion, and death occurs in 1 to 4 hours, however, Evans et al. (1990) find that 46 of his 47 ***T. talpoides*** died within 36 hours of baiting, and the last one died 3 days after baiting. Anthony et al. (1984) report that most gophers die within 4-1/2 hours after consuming 102 milligrams of 0.5 percent strychnine-treated oats, but *"one surviving gopher consumed over 125 milligrams (about 272 milligrams per kilogram [of body weight] per day) for four consecutive days with no ill effects."* They also report that 99 percent of the strychnine recovered in carcasses remained in the gastrointestinal tract.

Strychnine does not bioaccumulate in bodily tissue, and if the animal lives, the body completely eliminates it in a few days. If a poisoned animal can survive the first 24 hours after one dose of strychnine, it will probably recover and show no long-term deleterious effects (Cheney and Vander Wall 1985). Some gophers survive by eating only a sublethal dose of poisoned bait, or by caching the bait because of the availability of other preferred foods.

If a baited animal has a large amount of food in its stomach, the passage of strychnine through the intestinal walls slows considerably, thus allowing it to be metabolized or eliminated with fewer physiological consequences. Intense physical exertion after poisoning can hasten the lethal effects. If gophers ingest low doses of strychnine on a regular basis, the toxin may accumulate in the gastrointestinal tract faster than the body can eliminate it, thus achieving a lethal amount (Cheney and Vander Wall 1985).

Sublethal quantities of strychnine do not apparently affect pocket gopher behavior (Marsh and Howard 1978 and Lee et al. 1990). Howard et al. (1968) find that even though ***T. bottae navus*** got repeatedly sick on sub-lethal doses of strychnine, they continued to ingest strychnine-treated food until they eventually died. Gophers in their study actually preferred strychnine-treated grain over untreated grain, did not develop bait aversion, and when fed an exclusive diet of slowly increasing concentrations of strychnine-treated wheat, survived longer than the researchers expected, but the survivors *"were extremely susceptible to*


Installing a bottle trap.

extraneous noises." Then Howard et al. (1985b) find that, *"Six of 73 gophers **[T. bottae]** exposed to strychnine daily developed a tolerance to strychnine..., [but] the result is by no means conclusive..., [and] if a gopher eats only a sublethal amount of grain each time, it can tolerate even more of the toxicant."* Lee (1986) finds that some ***T. bottae*** *"develop a tolerance for strychnine alkaloid baits and were able to exist on an exclusive diet of these baits."*

Lee et al. (1990) studied four ***T. bottae,*** which *"freely consumed 0.5% strychnine bait, and 3 of them also 1% strychnine bait, for long periods without dying, whether or not nontoxic alternate bait was present. After one gopher (#5) was taken off its 1% strychnine wheat diet for 44 days, it lost its physiological tolerance to strychnine and died the first day when exposed to a free choice of non-toxic and 1% strychnine wheat. It consumed only 7 mg/kg of strychnine before dying, whereas another gopher (#42) was able to survive on a mean daily consumption of 275.8 mg/kg of strychnine in a no-choice situation over a period of 28 days. This is almost 40 times the lethal dose of the other animal."*

Some researchers have speculated that ***T. bottae*** may have developed a genetic resistance to strychnine, but Marsh (1992) live-trapped pocket gophers and force fed them doses of strychnine by gavage, and found that supposition false. However, he noted *"that some gophers acquire a tolerance to strychnine if they feed on the bait over time and do not consume a fatal dose at the initial feeding."* Lee et al. (1990) find that the natural feeding pattern of ***T. bottae*** includes *"not ingesting a large amount of food at any one time...[which] may help gophers survive various kinds of toxic food items found naturally in their habitat."* This process allows the toxic substances to be *"excreted in urine or metabolized, or nearly so, before engaging in another feeding bout."*

Tickes et al. (1982) find that ***T. bottae*** show no bait shyness, even after ingesting sublethal doses. Conversely, Marsh and Howard (1978) find that when ***Thomomys*** ingest sublethal amounts of strychnine-treated bait, they tend to shy away from the bait material, but not the taste of strychnine. Therefore, the researchers suggest changing brands or type of bait. For example, Wang et al. (1986) suggest using strychnine-treated wheat or milo instead of oats if the target gophers become bait shy. Hungerford (1976) also suggests the use of more than one kind of bait, since *"laboratory studies have shown that individual gophers differ greatly in amount of food consumed and preferences for various foods."*

When the EPA questioned the *"systematic [probably meant systemic] action of strychnine in orchards"* in Washington State, Hunter (1980) reported that all samples of apples from an orchard treated for gopher control tested negative for strychnine (see pages 38-42).

Zinc Phosphide: This black or grayish-black metallic powder remains stable when dry, and has a disagreeable phosphorus odor. Although insoluble in water, once swallowed it produces phosphide gas when it contacts dilute acids such as those that occur in the stomach. After the bloodstream absorbs the gas, convulsions, paralysis, coma and asphyxia follow. Death *"takes several hours or occasionally several days"* (Forest Service Handbook 1978). If used repeatedly, target rodents develop bait shyness (Askham 1988).

The EPA registers this compound for mice, gophers and other vertebrate pests. Johnson (1992) states that *"zinc phosphide is highly to extremely toxic to both mammals and birds [but] is several times more toxic to rodents than to carnivores."* Bell and Dimmick (1975) state that *"the highly nonspecific toxicity of zinc phosphide provides some cause for concern when widespread application in fields or forested areas is contemplated,"* but Marsh (1985) says that although zinc phosphide has *"very little potential for secondary poisoning of predator or scavenger species that may consume dead rodents,"* it has had mixed success in field applications. Tickes (1983) compared eight different formulations of zinc phosphide against ***T. bottae,*** and had control percentages that ranged from 5 to 22 percent, probably owing to the availability of a preferred altemative food, alfalfa.

Barnes et al. (1982) find that *"the zinc phosphide-grain baits produced inconsistent, but generally poor results for control of [**T. mazama**..., however,] prebaiting would improve gopher acceptance, but we do not believe prebaiting would be economically feasible for most gopher control programs."* They also state, *"Zinc phosphide baits generally were less effective [on **T. mazama**] than 0.5% strychnine alkaloid-oat bait...However, 0.75% zinc phosphide-carrot bait showed potential as a substitute for strychnine in particular areas."* They cited a study where *"both fresh root baits and grain baits coated with zinc phosphide were relatively ineffective against* **T. bottae** *in California."* These varied results may be attributed to poor bait acceptance or to the high humidity in gopher burrow systems, since zinc phosphide-treated bait, which deteriorates very slowly when kept dry, detoxifies rapidly if it absorbs moisture.

Lindsey and Evans (1983) and Barnes et al. (1982) find zinc phosphide carrot bait comparable to strychnine-grain bait in the control of ***T. mazama,*** however, carrot bait, like potatoes, raisins, prunes or other fruits or root vegetables, has other inherent problems, such as mixing the toxicant with perishable baits, maintaining their freshness during storage, and their handling and placement in the burrows. Nevertheless, Marsh and Steele (1992) state that *"zinc phosphide currently is registered for gopher control as loose grain and grain-based pelletized baits, but its effectiveness usually is considerably lower than results obtained with strychnine."*

Barnes et al. (1982) attributed some gopher mortality to zinc phosphide ingestion during grooming (see pages 38-43).

Diphacinone: An unpublished report by Eaton, J.T. & Company, Inc. (post 1988) explains that diphacinone causes internal bleeding by inhibiting the formation of blood clotting agents and by damaging capillaries. It further states that these symptoms *"are considered painless."* Poisoning progresses slowly, requiring repeated feedings–lots of bait available at all times–with death occurring in 5 to 7 days. Because diphacinone poisons so slowly, the target animals do not associate their symptoms with the bait, and bait aversion does not occur.

A draft report by Roy (1988) states that *Eaton's Answer®*, a 110 gram (4 oz.) diphacinone bait block that gophers readily accept, achieves controls of 60 to 84 percent with ***T. talpoides***, but qualifies his results with, *"The difference in the levels of control achieved..., may have resulted from availability of high quality alternative food [alfalfa]."* Tickes (1983) achieves a control of only 5 and 7.5 percent respectively in his comparison of two different dipacinone formulations, but he notes that the ***T. bottae*** in his test area also preferred the readily available local food (alfalfa). Vossen and Gadd (1990) achieved a 71 percent kill of ***T. bottae*** in California, and Campbell et al. (1992) achieved a 62 percent kill with ***Thomomys*** in southwest Oregon.

Campbell et al. (1992) achieved a 62 percent kill for diphacinone-treated plots compared to 72 percent for the strychnine-treated plots, and Sullivan and Sullins (1987) find that diphacinone averaged a 71 percent reduction in northern pocket gopher activity compared to a 78 percent reduction for strychnine bait, and that the gophers moved four radio-tagged, 113-gram bait blocks *"from 7 to 27.5 feet from their original placement locations."*

Although canine and avian poisoning have been reported from open bait sets, *"there is no field data on secondary poisoning for diphacinone in forest application,"* i.e. belowground or in covered bait sets (Eaton, J.T. & Company, Inc. post 1988). However, Jackson and Ashton (1992) find that canids *"seem more sensitive to diphacinone than other predators."* Bait blocks *"offer good selectivity against birds of all sizes, [and] except for gnawing rodents, herbivores do not apparently recognize them as a food item"* (Marsh 1985).

Mice and voles that feed on bait blocks may die aboveground, where they become possible prey for carrion-eating raptors or carnivores. Even though death may occur 5 to 7 days after ingestion of the bait, Eaton, J.T. & Company (post 1988) suggest the following factors that weigh against this scenario:

- Predators prefer live prey to carcasses. [Predators can capture poisoned animals after they have consumed the bait, but before they die.]
- Once ingested, the half life of diphacinone is about 7 days [about the time it takes for the poisoned animal to die].
- Affected animals excrete about 50 percent of the poison intact, which decomposes rapidly in the ground. [The company did not mention how much of the poison the animals can excrete before they die.]
- Of the other 50 percent, about five parts per million concentrates in the liver and the balance fully metabolizes. *"No detectable amounts have been found in other animal tissues, such as brain, muscle, fat, marrow or gut."*

Sullivan and Sullins (1987) find *"that diphacinone bait blocks and strychnine baits give similar efficacy over a short term, but we did not determine if bait blocks continued control beyond the resident population."* They also find that they baited *"an average of 1.5 acres per man-hour with strychnine bait using the hand probe method...[but only] treated 0.5 acres per man-hour with bait blocks."* Although diphacinone will probably not pass through unbroken skin, it may be absorbed through an open wound, therefore, applicators should wear gloves.

The management strategy for using a semipermanent bait block relies on the assumption that one bait application will control resident gophers and subsequent immigrant gophers. However, the present literature does not substantiate how the higher cost and supposed efficiency of bait blocks compares to successive strychnine treatments.

Because a gopher cannot consume an entire bait block in one feeding, some of it remains for the next gopher that occupies the same burrow system, or the same gopher in subsequent feedings. Campbell et al. (1992) find that when they recovered fragments of partially eaten diphacinone-treated bait bars from gopher feed caches, they sometimes came up with a total weight greater than the original bar they placed in the burrow. They attributed this to gophers bringing in fragments from other locations.

Because molded wax surrounds the treated bait, one assumes that the bait blocks maintain their longevity and palatability within the high humidity of the burrow environment. However, Sullivan and Sullins (1987) recovered bait blocks with a surface mold covering the uneaten portions, and whose texture had changed from an original hard, brittle composition to a soft, crumbly one. Campbell et al. (1992) also find that *"the condition of bait blocks varied considerably from remaining intact to being mushy and moldy, all within the same time period."*

This product has two disadvantages: 1. Gophers eat more toxic bait than necessary to kill them. (Campbell et al. (1992) find that the gophers eat approximately 50 percent of the bait block), thus leaving less for succeeding gophers. 2. Placing these bait blocks in the burrow systems costs much more than baiting with strychnine-treated oats.

Chlorophacinone: Another anticoagulant similar to diphacinone, it reduces the clotting ability of blood, and may in extreme cases, cause bleeding. Baroch and Poche (1985 or 1986) cite a study in California that resulted in a zero percent mortality, and another in Colorado that achieved a 95 percent mortality rate in 3 to 14 days. Due to the low (0.005%) concentration of active ingredient in the bait (the same as for commensal rodents), and since poisoning is cumulative, the label suggests placing one-half cup of bait in each of two to three sets per burrow system. This indicates that the gophers must consume a very large amount of bait for effective control, and therefore, it may not become very popular with land managers, who would have to purchase, store, transport and handle a large volume of treated bait.

A test by Canadian Bio-Scientific Consultants Ltd. (1975) finds *RoZol*® superior to strychnine. Patrick and Leoni (1984) achieved a 60 to 75 percent kill, and Voss and Gadd (1990) an 80 percent kill of ***T. bottae*** in their California studies, and Tickes (1983), also dealing with ***T. Bottae***, achieved a zero percent control with three different formulations of chlorophacinone, the latter probably attributable to the availability of a preferred alternative food, alfalfa.

Methods of Baiting

By Hand: A relatively slow but very reliable procedure, it provides safe and effective control when performed properly. The applicator uses a probe to locate a burrow, creates a hole, deposits the toxic bait in the tunnel, and seals the hole to exclude light. Using a mechanical bait dispenser allows the job to go faster because the operator dispenses the bait with the probe. Covering the probe holes reduces the chances that non-target wildlife will encounter the bait, or that the gophers will bury it during their tunnel maintenance activities.

To bait gopher burrows with diphacinone- or chlorophacinone-treated bait blocks, the bait applicator must physically excavate an active burrow and place the bait blocks in the tunnels. Minore (1978) reports with a touch of frustration and discouragement, *"Direct control of gophers is laborious and expensive. Baiting is cheaper than trapping, but neither work well where gophers are present in surrounding areas.* [Then quoting from Larsen, Lawrence P. 1975-1977, Field notes at the Medford District Office, Bureau of Land Management, Medford, Oregon] *'The physical job of baiting runways 4 to 8 inches below ground surface over any large area with 50-70 gophers per acre* [an average of one gopher burrow system every 25 to 30 feet] *is very demoralizing, 'and'...the unoccupied burrow systems are rapidly reoccupied by invasion from adjacent populations.'"*

By Machine: Marsh (1992) states, *"The development of the gopher burrow builder revolutionized pocket gopher control and has led to widespread extensive and concentrated gopher management which has been successful beyond expectations."* A burrow builder provides the fastest means to apply toxic grain bait, and *"is considered the most efficient means of achieving direct control"* (Barnes 1974). In this method, a tractor drags a device with a subsurface torpedo, that when pulled through an area, creates artificial burrows and dispenses toxic bait (strychnine- or zinc phosphide-treated grain) in them. Since these newly-created borrows intersect existing active burrows, gophers explore them and find the toxic bait. The number and distance between treated rows depends on the density of the gopher sign, i.e., the number of mounds. The label for 0.5 percent strychnine-treated steam rolled oats suggests rows 20- to 30-feet (6- to 9-meters) apart, depositing 1 to 2 pounds of bait per acre (1.1 to 2.2 kilograms per hectare), and the label for 2 percent zinc phosphide-treated bait suggests rows 4- to 5-feet (1.2 to 1.5 meters) apart, depositing 2 to 3 pounds of bait per acre (2.2 to 3.3 kilograms per hectare). I could not find any mention in the literature of a machine that can dispense the anticoagulant bait blocks.

Springtime ground conditions generally provide the best opportunities to use a burrow builder. Barnes et al. (1970) find that a D-6 *Caterpillar*™ had more than enough power to pull the burrow builder and move debris, while it maintained a constant speed. The burrow builder, when attached to a free-floating hitch, worked better than when attached on a 3-point hitch pulled by a utility tractor. The 3-point hitch allows a sliding motion and drag on the subsurface torpedo, which creates poor quality burrows. Also, the utility tractor cannot safely maneuver on steeper slopes, since it has to lift the torpedo from the ground more often to keep from rolling over, thus leaving more areas to treat by hand, and more opportunities to spill bait on the surface.

Economical on flat areas with a large gopher population and relatively moist sandy soil, this method works very well on farmland. A heavy duty tractor has the power needed to pull the machine through a timber sale area and to handle the residual slash, roots, and rocks, all of which prevent the creation of good artificial burrows, but needs more power to treat areas with wet and sticky soils, which accumulate on the packing wheel and cause the bait dispenser not to open and close properly, thus leaving too much or not enough bait in the burrows. Also, when the operator raises the torpedo to clean out collected debris, to avoid obstacles in the treated area, and to turn around, some poisoned grains may drop on the surface of the ground, which, if eaten by nontarget species, can cause nonintended mortality (see pages 38-43).

Other disadvantages include: dry soils may cause the artificial burrows to collapse more easily, thus covering the bait; the ground disturbance caused by the use of this machine enhances forb growth, which in turn, supports more gophers; the machine-made tunnels provide instant habitat for reinvading gophers to occupy; running another machine over the area causes extra site compaction; the need to hand bait all the scattered portions of the treated area that the machine cannot reasonably treat, such as steep pitches and portions with too many roots or rocks; the failure of tractor drivers to realize the sensitivity of the

Bait set near three mounds.

Gopher tunnel created by burrow builder.

bait; and the loss of strychnine (15 to 25 percent) from the formulation that seems to occur during machine baiting operations (Evans, Campbell and Engeman 1990). They also suggest that this loss of strychnine is inherent in the bait formulation coating on the grain, and should be corrected for.

Despite these disadvantages, Evans et al. (1990) report that they did not evaluate one burrow builder unit that they had treated with 0.75 percent strychnine because they believed that the soil had insufficient moisture to maintain adequate burrows. *"Numerous excavations of artificial burrows revealed poorly formed tunnels with up to 10 cm (4 in) of loose soil over the bait."* However, after 3 weeks, their evaluation revealed a 100 percent control on that area. They also experienced *"a substantial loss of strychnine between time of mixing and time of application with the burrow builder,"* but could not determine the cause, since both their burrow builder bait and their hand bait (which suffered no loss in strychnine content) *"were formulated in the same way with the same ingredients."*

Toxic Baiting Summary

The use of toxic baits remains the most common method to control gopher depredation. Although very effective, weather, terrain, or inexperienced crews sometimes hinder operations. Excessive rain can saturate the upper soil layer too much to apply the bait successfully; or not enough rain leaves the soil too dry, which causes the gophers to avoid the upper portions of their burrow system. Steep terrain can cause safety hazards for the tractor operator. For successful control efforts, bait applicators must identify occupied burrow systems, but inexperienced crews treat inactive burrow systems–spending money, but having no effect on gopher populations. Applicators must place bait in a main runway of an active burrow system with as little disturbance to the burrow as possible. During their tunnel maintenance activities, gophers would probably bury any bait mixed with soil in a disturbed tunnel, or any bait placed in lateral tunnels.

Tickes (1983) finds gopher bait preference very complex and influenced by many factors including but not limited to: deprivation level, dehydration level, gender, previous experiences with food materials, and the gophers' individual preferences when the bait competes with equally accessible alternative–and maybe preferred–foods.

Better control results when a second baiting follows the first a couple weeks later, thus prolonging the time the gopher population can recover. For relatively small gopher populations, spring is the best time to bait for controlling the existing population before the birth and weaning of the young of those that survived the winter. For relatively large populations, fall is the best time to bait in order to reduce the population before the dormant season, when most of the feeding on conifers occurs. Barnes (1973) "*conducted a preliminary study of winter bait acceptance,*" but had negative results.

"Strychnine is considered to be the best [registered] poison for control of pocket gophers" (Nelson 1969). Applied according to the label instructions, the hand application (below ground) of 0.5 percent strychnine-treated oat bait remains the most efficacious and cost-effective method of pocket gopher control in the forested areas of northeast Oregon. Surface-placed strychnine bait - which violates the label, and therefore, is illegal–will probably not be taken by gophers. It could, however, be consumed by, and kill nontarget animals.

Marsh and Steele (1992) state that *"direct control of pocket gophers with poison bait...will remain a major forestry practice for the foreseeable future."* Successful gopher control depends on the quality and toxicity of the selected bait, a well planned baiting program, and constant monitoring from prescription, through application, to post-baiting observations.

Concerning the first of these aforementioned points, Evans et al. (1990) state that *"retention of strychnine on bait and using high quality steam rolled oat groats (oats without hulls) were two important factors affecting efficacy of the bait."* Concerning the third point, they found that the private pesticide contractor for their study had baited less than 60 percent of the sample plots, and only about 40 percent of the baited plots met contract standards for number of sets. Of the sets checked, the contractor placed an average of 1/4 teaspoon of bait per set instead of the required one teaspoonful. Therefore, proper contract administration ought to increase the probability that the funds used to control the offending gopher population are well spent. Birch (1987) also stresses effective contract administration to achieve acceptable results in the field.

Secondary and Nontarget Poisoning

Pocket gophers become pests when their economic or aesthetic effects impact human activities beyond a point determined by the land manager, who then seeks to reduce that impact in the most economical manner, by either exclusion or control. The objective of exclusion or control must not only consider maximum efficacy on the target species, but also ***minimum*** effect on nontarget species. *"In this context acceptable [sic] nontarget impact is a complex and variable quantity, which changes with the species, time, place, and value system of the observer"* (O'Brien 1986).

The initial design of the control process must concurrently address the impacts to both the target and nontarget species, not merely modify a preconceived control process to minimize the impacts to nontarget species, and *"because a species' pharmacological sensitivity to a toxin may bear no close relationship to its ecological vulnerability..., there is a need to evaluate nontarget hazard in actual field situations or closely analogous circumstances"* (O'Brien 1986).

The careful consideration of the appropriate control system on nontarget species need not compromise the ultimate efficacy on the target species. Since a control program will most likely affect nontarget species most similar in socioecological characteristics, the land manager can improve control by effectively exploiting the similar and contrasting characteristics of all the associated species in the treated area.

The EPA disallowed the aboveground use of strychnine bait to reduce the risk to nontarget wildlife species. The overriding interest at that time concerned endangered and other predatory species becoming secondarily poisoned by consuming the carcasses of rodents killed with strychnine-treated bait.

Hallett and Gilbert (1987) state, *"Our present knowledge of the risks of secondary poisoning resulting from application of vertebrate pesticides in forest management is rudimentary... Emphasis has been placed on developing suitable laboratory procedures for assessing the likelihood of secondary poisoning...Unfortunately laboratory studies can only indicate whether a species is susceptible...The actual risks of [secondary] poisoning under natural conditions will depend on many factors (e.g., the behavior of the prey species after ingesting poison, the foraging behavior of the predator or scavenger, and the period of exposure)...Few intensive field studies of secondary poisoning have been conducted."* They later state, *"Laboratory trials are likely to provide misleading indications of the probability of secondary poisoning."* They affirm that *"currently used vertebrate pesticides may potentially poison predators or scavengers feeding on target species, [however,] the degree of risk is unknown during control of rodent pests in Pacific Northwest forests."* They also cite another study that though *"consistent with earlier hazard assessment studies, indicated a high probability of secondary poisoning of mammalian predators (canids and felids), but very low risk for raptors. The lower susceptibility of raptors appears to be due to their generally high LD 50s, evisceration of prey before ingestion, and perhaps refusal to eat tainted meat."*

Secondary hazard potentials vary by the rodenticide ingested by the pocket gophers, and the rate the researchers apply the bait, i.e., the label-recommended rate or an experimentally higher dose, two factors not always fully explained by authors in discussing secondary poisoning. Among others, Hedgal et al. (1986) find secondary poisoning with *Compound 1080*™, but that chemical *"is currently neither registered nor available for any type of rodent control" (Marsh 1992).*

If secondary poisoning would occur, the target species' population growth would probably increase to a point greater than prior to the control attempts, because the predators would die, and the prey have higher reproduction rates. Hallett and Gilbert (1987) summed up their opinion by covering all the bases, *"The problems of secondary poisoning of wildlife might be of minor ecological importance in the management of Pacific Northwest forests...[but] the potential [sic] for secondary poisoning is great in the control of small mammals. The local application of poisons working at this level, however, is unlikely to result in the same types of biological effects witnessed with, for example, DDT. Although the evidence to date does not indicate that secondary poisoning is an important problem, the obligation is clearly ours to demonstrate that this is the case...It is also incumbent on us to reduce the possibility of secondary poisoning."*

Basically, any attempt to quantify secondary hazards from data based on controlled field experiments can lead to misleading conclusions. Since mammalian and avian predators occupy the upper portions of the ecological pyramid, scientists commonly study only a relatively small number of them in delineated areas. Therefore, all extrapolations of these data, generally based on small sizes, *"greatly increase the possibility of drawing improper conclusions on the basis of what may be atypical results"* (Record and Marsh 1988).

When assessing potential secondary hazards, land managers must clearly identify the biological and ecological factors as best they can in order to comprehend the complexities of the local situation, thus providing a better and more realistic interpretation of the data collected, including:

- ❑ The chemical and toxicological properties of the agent applied to the environment,
- ❑ The site and speed of absorption at differing amounts of bait ingested,
- ❑ The rapidity with which the target species excretes the toxicant or breaks it down, and if the breakdown products also have toxic properties,
- ❑ The organs or tissues that retain the toxicant,
- ❑ The latent period, i.e., the time between ingestion and the onset of symptoms and/or death, which allows time for the target species to metabolize and/or excrete the toxin, thus reducing the toxic residues in the body.

Strychnine: Because a possibility exists that strychnine-treated gophers can be taken as prey, secondary hazards are theoretically possible. Hedgal and Gatz (1976) report that *"to measure secondary effects we equipped 36 raptors and 36 mammalian predators with radio transmitters. We detected little, if any, effect on radio-equipped raptors and mammalian predators. Red-tailed hawks **(Buteo Jamaicensis)**, American kestrels **(Falco sparverius)**, great horned owls **(Bubo virginianus)**, badgers **(Taxidea taxus)**, striped skunks **(Mephitis mephitis)**, red fox **(Vulpes fulva)**, and a coyote **(Canis latrans)** were intensively radio-tracked during treatment; those that utilized treated fields all survived. Mammalian predator tracks and diggings were frequently observed on the burrow-builder tracks after treatment. Red-winged blackbirds **(Agelaius phoeniceus)** were selected as a representative of seedeating birds. We marked 100 territorial males on both the treated and control area and control area and monitored them druing the treatment. Even though some treated grain was available on the surface and marked*

*birds were observed feeding in treated fields, we did not detect any detrimental effects. Nevertheless, we found one treatment-killed mourning dove **(Zenaida macroura)** [with strychnine residue in its crop]."*

They also cite:

- The case of a radio-tracked, red-tailed hawk and a great horned owl that *"were frequently found in or near treated fields and were still present two months after treatment."*
- A red-tailed hawk that fledged two young from a treated area. They found pocket gopher ***(G. bursarius)*** and ground squirrel carcasses at the nest site, *"but neither contained strychnine residue."*
- *"Of the mammalian predators on the study area, badgers **(Taxidea taxus)** probably have the highest percentage of pocket gophers in their diet, [and in that area] badger scat is predominantly pocket gopher remains...Since badgers expend considerable effort digging for pocket gophers,...those found dead underground could present a secondary hazard to badgers."*
- One skunk died after eating a strychnine-killed gopher.

Their study concluded *"that the control of pocket gophers with strychnine bait, properly applied with the burrow builder, is a relatively safe procedure with few hazards to non-target wildlife."* However, Campbell et al. (1992) cite a case where birds carried one radio-collared pocket gopher 1300 feet, another 237 feet, and another 185 feet from their normal locations in a strychnine oat-treated plot.

"Gallinaceous birds are generally not vulnerable to strychnine, partly because they do not readily consume strychnine treated bait [its color and shape do not appear as its natural food]...and partly because strychnine baits are low in toxicity to gallinaceous birds" (Fagerstone et al. 1980). Hegdal and Gatz (1977) indicated that the use of surface-applied strychnine bait threatens seed-eating birds, and Hegdal (1987) states, *"The hazard to birds can be drastically reduced by placing the [strychnine] bait underground,"* which by EPA registration since 1983, is the only legal method to apply strychnine-treated bait.

Strychnine is a fast-acting compound, so death occurs relatively quickly following ingestion of a lethal dose. Since pocket gophers almost always die underground (Lindsey and Evans 1983 and Barnes et al. 1985), each in its own burrow system and over a period of several days, they are not only physically separated from each other, but each carcass only contains a small amount of strychnine (Barnes et al. 1985).

Because gopher predators have a greater body mass, they must consume many strychnine-killed prey for them to accumulate a lethal dose of strychnine. The likelihood is slim that a gopher predator would find and consume, in a relatively short period of time, enough gopher carcasses before they deteriorated to the point of not being an acceptable meal. Also, some predators do not eat the gastrointestinal tract, where most of the strychnine remains.

Barnes et al. (1982) find that in a test with 20 radio-collared ***Mazama,*** 19 died below ground, and *"One gopher was found dead aboveground, but it had previously been located 60 cm belowground in a moribund condition. We suspected the animal was poisoned [0.5% strychnine oats] and then pushed out of its burrow system by another animal."*

In their review of possible cases of secondary poisoning of coyotes and foxes by consumption of strychnine-killed rodents, Hegdal et al. (1981) states that *"it appears that most secondary poisoning caused by strychnine rodenticide baits depends on whether or not the stomach or intestines of the poisoned rodent are consumed by the mammalian predator."* They also cite a study where *"no coyotes or badgers were found dead during a prairie dog control operation in Montana, although they were observed feeding on the carcasses of dead prairie dogs [in a strychnine-baited area]."*

National Forest managers have put a lot of reliance on strychnine bait because no other available rodenticide provides such effective control for large-scale use against gophers. However, some wildlife biologists believe that the use of strychnine poses potential hazards to nontarget wildlife, including T&E species (Barnes et al. 1982). The USDI Fish and Wildlife Service (Hegdal and Gatz 1976), finds that *"although laboratory studies have shown that theoretical possibility of primary and secondary poisoning of several desirable wildlife species, available field data are limited and contradictory."* When referring to pocket gophers, the Bureau of Sport Fisheries and Wildlife finds that *"strychnine offers slight hazard of secondary poisoning,"* and when referring to the use of strychnine-treated salt blocks for porcupine control, state, *"because porcupine carcasses are readily eaten by all of the major carnivores found in the west, strychnine, with its small hazard of secondary poisoning, is the selected toxicant"* (Nelson 1969).

Littrell (1990) states that ground squirrels and gophers exposed to strychnine allowed secondary poisoning of predatory and scavenging birds, including *"Canada geese **(Branta canadensis)** being killed by spillage of a gopher **(Thomomys sp.)** bait formulation used at a park, and of at least one golden eagle **(Aguila chrysaetos)** killed by consumption of a poisoned Belding's ground squirrel in an area strychnine was being used for gopher control."* Although Littrell did not offer specifics on this latter case, I would like to mention three points:

- ❑ Ground squirrels, unlike pocket gophers, spend a good portion of their time above ground, where they present many opportunities for capture by raptors.

- ❑ Ground squirrels transport food items in their mouth, which allows the strychnine to get absorbed through the mouth easily, possibly affecting the ground squirrel's behavior on the surface.

- ❑ A ground squirrel ingested with a mouthful of strychnine-treated grain, which it had no time to metabolize, could have a fatal effect on a raptor.

Sublethal ingestion of acute rodenticides can cause target or nontarget animals to stop feeding. This adverse reaction to a bait can be a momentary response or a longlasting condition cued by vision, taste, texture, or odor. Reactions vary by species, but such adverse conditioning (bait/toxicant-shyness), results from an atypical sensation, or from becoming ill as a result of a sublethal dose of the toxic bait. Since other small rodents utilize gopher burrows, the impact of strychnine on nontarget species will vary among different habitats and areas. Each species' particular habitat needs and season of use can affect their exposure to and their acceptance of the bait. Mice, chipmunks and ground squirrels fall into this category. Anthony et al. (1984) suggest baiting as late as possible in the year in order to reduce the inadvertent poisoning of golden-mantled ground squirrels, which make their greatest weight gain just prior to their hibernation.

Evans, Campbell, and Engeman (1990) systematically searched their study area once per week for 7 weeks post treatment. They found 13 pocket gophers ***(T. talpoides)***, five western jumping mice ***(Zapus princeps)***, and two deer mice ***(Peromyscus maniculatus)*** above ground. Of those, they found only three gophers and one jumping mouse in a condition to check for residual analysis. The rest were partially consumed by carrion-eating insects or in a state of advanced decomposition (poor prospects for consumption by raptors, canids, or felids). Other interesting observations in this study include: the 1.00 percent strychnine formulation plots yielded nine animal carcasses, and the 0.75 percent formulation yielded 10 carcasses (both formulations above the present EPA-recommended potency); the 0.5 percent formulation (recommended potency) yielded only two carcasses, both of which the researchers found below ground; the control units, where the bait had 0.0 percent strychnine also yielded two pocket gopher carcasses. The authors concluded that the *"hazard potential of the 0.50% bait was quite low."*

Anthony et al. (1984) found that of the 53 radio-collared golden-mantled ground squirrels in their central Oregon study area for pocket gopher control, 26 died, 23 within 5 days after baiting. Of the 26 carcasses, strychnine caused the death in 25 of them. They found 19 above ground, five below ground in pocket gopher burrow systems, and two in their own nest. Badgers killed two treatment squirrels. *"Of 28 squirrels on the control plot, none were found dead, [and] two were taken by badgers...No other animal species were found dead."* Despite the fact that nontarget animals died, strychnine-killed animals on the ground surface did not pose an apparent secondary poisoning problem for rodent predators.

The following year, they (Anthony et al. 1984) rebaited the gopher plots. Of the 64 radio-collared ground squirrels (24 on the baited plots and 40 on the control plots), *"none of the ground squirrels died as a result of the strychnine bait. No bait was found in nine excavated ground squirrel nests."* Anthony and Evans (1984) find that the underground baiting for pocket gophers can significantly reduce golden-mantled ground squirrel populations, but the area adequately repopulates within 1 year, concluding that, *"We believe that underground baiting forest pocket gophers with 0.5% strychnine-treated grain normally will not cause unreasonable long-term adverse effects on non-target wildlife species."*

Evans et al. (1990) report the aboveground recovery of five deer mice ***(P. maniculatus)*** in an experimental plot treated with 1.25 percent strychnine bait, a much higher concentration than the 0.5 percent mandated by the EPA for pocket gopher control. They also found 13 gopher carcasses above ground in the hand-baited area, and two gophers in the burrow builder-treated area, though *"some were in the 0.5% study units."* I must emphasize that a 1.25 percent formulation kills much more rapidly than a 0.5 percent formulation.

Fagerstone et al. (1980) also report the loss of two deer mice ***(P. maniculatus)*** in a gopher-treated area. Their study also included 30 radio-collared yellow pine chipmunks ***(Eutamias amoenus)*** and one northern flying squirrel ***(Glaucomys sabrinus)***. The latter and 24 chipmunks survived until the end of the study. Two chipmunks died and their partially consumed carcasses had strychnine residues. The authors believed that these chipmunks *"ate a sublethal dose of strychnine, survived it, and were later taken by predators."* Three transmitter signals were lost prior to the treatment, and they found one transmitter beneath a kestrel's nest three days after baiting. They concluded, *"We noticed no [secondary] hazards in this study [and] found no hazards to mammalian predators in either underground or aboveground strychnine baiting programs."* Note that this study took place before the EPA's 1983 prohibition of aboveground use of strychnine-treated bait.

Apa et al. (1991) find that surface-applied strychnine-treated oats (now a prohibited practice as stated on the label) caused a significant reduction of horned larks ***(Eremophila alpestris)***, a granivorous passerine that inhabits black-tailed prairie dog habitat. Uresk et al. (1987) report a decrease in horned lark densities with strychnine-treated oat bait. However, horned larks feed on the ground, and the researchers made no mention as to whether they applied the bait above or below ground. Although they tested for control of prairie dogs with zinc phosphide and strychnine-treated oats, their study resulted in highly variable data and presented inconclusive evidence of nontarget poisoning.

Barnes et al. (1985) *"detected little or no strychnine in carcasses of other animals recovered post-treatment...and found no evidence that concentrations of poisoned animals were available to predators or scavengers. Small mammal populations were not adversely affected by baiting...and animals captured alive post-treatment contained no detectable strychnine residues."* They also noted that *"the mean strychnine concentration on bait recovered from nests and food caches was about half that of samples taken before application,"* indicating that the strychnine broke down rapidly in the burrow environment, thereby losing its toxicity, that is, the bait that was 36 to 51 percent active the day of application was only 20 to 27 percent active 10 to 12 days post-treatment. The researchers suspected that the *"gathering and storing activities of pocket gophers* ***[T. talpoides]*** *caused sloughing of the adhesive agent and strychnine."*

Anthony et al. (1984) find that the *"secondary hazard potential to [great horned] owls and [red-tailed] hawks were [sic] judged to be minimal, [but] wild mustalids as large as mink could be adversely affected by consuming the gut content of strychnine-killed golden-mantled ground squirrels."* They also found that of five great horned owls *"tested on one whole strychnine-killed ground squirrel, one rejected the GI tract, and another regurgitated an undigested stomach and liver. Of five owls [which were] presented ground squirrel stomachs sewn into eviscerated deer mice, one regurgitated all three undigested mice and another rejected part of a mouse and the stomach of a poisoned ground squirrel. In the 16-day chronic feeding test, treatment owls consumed carcasses but avoided the GI tract of poisoned ground squirrels in 48% of the feedings. Controls did not regurgitate untreated mice or ground squirrels, and only occasionally (less than 5%) rejected GI tracts...Almost all (99%) of the strychnine occurred in the gut of the poisoned squirrels."* They concluded that *"secondary hazard potential to owls and hawks were judged to be minimal."*

Laboratory tests by Cheney and Vander Wall (1985) find considerable inter- and intraspecific variation in a raptor's response to strychnine. Sublethal doses of strychnine cause such symptoms as uncoordinated and agitated movements and severe tremors in great horned owls, which intensify following exertion. The red-tailed hawks appeared less sensitive. In them, the strychnine caused highly excited and incoordinate behavior, but no tremors. The researchers concluded that *"concentrations of strychnine alkaloid far below those causing death have potentially important behavioral consequences for those raptors...Effects, even when minor, can have harmful consequences if they occur during critical periods of the annual cycle. Since these raptors did not avert to even severe reactions to strychnine they may, in the wild, continue to ingest strychnine-poisoned prey. Even small doses of strychnine, if frequently ingested, can summate and have debilitating consequences."*

Feeding behavior also affects the absorption of a toxin. If a raptor swallows a rodent whole, it has more time for its gastrointestinal tract to absorb and excrete the toxin in the rodent's gastrointestinal tract. But a raptor that dismembers its prey can have problems. If it eats the entrails separately, where almost all of the strychnine residue remains, the toxin can act more quickly. If it rejects the entrails, it receives little to none of the toxin, since the other body tissues do not assimilate strychnine. The only exception to this scenario would be if the raptor swallows a gopher whole–or eats the head–with poisoned grain still in the cheek pouches. This is an unlikely possibility, since a pocket gopher would probably carry the bait to its nest or a food cache or consume it within the burrow system rather than come to the surface with full cheek pockets.

Marsh (1985) states that despite the rodent control conducted on millions of acres annually in California, the incidental loss of nontarget wildlife is so unlikely that few cases are able to be documented. Also, since scavengers rapidly remove or consume available carcasses, few remain on the surface for any length of time. Therefore, to assure the least possible damage to nontarget wildlife, certified applicators must apply rodenticides strictly according to the label directions.

Notwithstanding, Evans et al. (1990) cite a case where one of their 47 radio-collared pocket gophers died above ground in an area treated with strychnine bait, and Dreisbach (1987) in his Nez Perce National Forest report, mentions *"Non-target species killed [and] pocket gophers dying above ground"* as problems he encountered during the baiting season, but offered no other details.

Although I found no literature on the immediate and long-term effects on nontarget invertebrates caused by rodenticides, Deisch et al. (1989) find that zinc phosphide treatment for black-tailed prairie dog ***(Cynomys ludovicianus)*** reduced ant ***(Formicidae)*** populations and strychnine reduced wolf spider ***(Lycosidea)*** populations in the short term. Since spiders–unlike ants–do not consume grain, their populations probably declined because their prey consumed poisoned grain. Ground beetles ***(Carabidea)*** increased after 1 year, probably attributable to *"biotic and abiotic habitat alterations due to lack of prairie dog activities."* The authors noted no changes in the densities of spider mites ***(Tetranychidae)***, which suck plant juices on live vegetation, crickets ***(Gryllidae and Gryllacrididae)***, which feed on plant foliage, *"dead and dying insects, hair, hide and carrion,"* darkling beetles ***(Tenebrionidae)***, which consume detritus, but will eat seeds, and dung beetles ***(Scarabacidae)***, which scavenge dung, carrion and decaying vegetable matter.

Zinc Phosphide: Bell and Dimmick (1975) find that when fed zinc phosphide-killed voles, some foxes ***(Vulpes fulva*** and ***Urocyan cineroargenteus)*** and owls ***(B. virginianus)*** exhibited different behavior patterns from those established prior to the feeding of the tainted voles. These behaviors *"may reduce their resistance to environmental pressures which could prove fatal."* They also concluded that *"certain factors may serve to prevent or reduce the occurrence of 'secondary' poisoning to wild predators. Some individual predators may be able to detect animals poisoned by zinc phosphide by olfaction or taste, and subsequently reject them as food."*

Hegdal et al. (1981) report on studies of fox, mink, domestic cats and dogs all fed with zinc phosphide-killed rodents. They concluded, *"Some secondary poisonings caused by zinc phosphide have been demonstrated. However, the strong emetic action of zinc phosphide on predators and detoxification of zinc phosphide in the rodents' gut combine to make secondary poisoning of predatory mammals highly unlikely in most situations,"* especially if the predators, e.g. badgers, eviscerate the carcass and do not consume the stomach and intestines. Marsh (1987b) and Johnson (1992) basically confirm the conclusions of Hegdal et al. (1981).

Barnes et al. (1982) found a dead Belding ground squirrel ***(Spermophilus beldingi)*** 36 inches below ground in a nest of a radio-collared gopher with a mutilated carcass of a gopher and a cache of 0.92 percent zinc phosphide-oat bait, and a dead golden-mantled ground squirrel ***(S. lateralis)*** 42-1/2 inches (1.09 meters) belowground in a nest with a carcass of a gopher and 0.5 percent strychnine-oat bait. They also recorded a dead deer mouse and a golden-mantled ground squirrel on the surface of the strychnine-baited plots, and three dead deer mice ***(P. maniculatis)*** in their nests 3 inches below ground within 3 feet (.9 meter) of a zinc phosphide bait set. Note that nontarget animals can pick up zinc phosphide-treated bait when applied on the ground surface for species other than gophers.

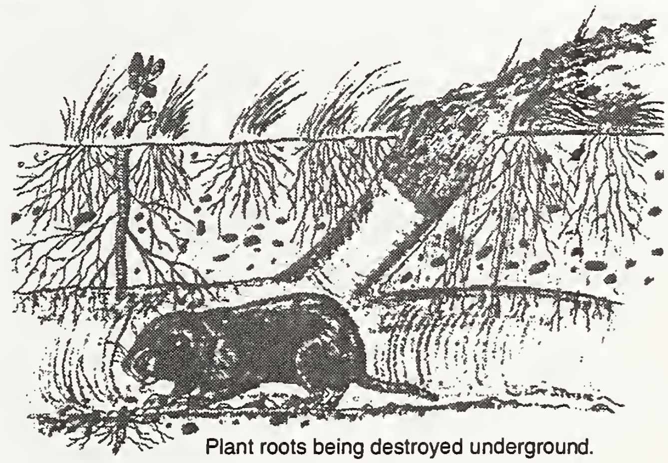
Record and Marsh (1988) find zinc phosphide *"a good example of a rodenticide which breaks down relatively rapidly in the intestinal tract and presents little secondary hazard to predators."* Hegdal (1987) also finds minimal secondary hazards, but substantial primary hazards to nontarget rodents, waterfowl, gallinaceous and seed-eating birds, while Apa et al. (1991) find that surface-applied zinc phosphide *"caused no measurable reduction"* to the 50 species of birds in their study area of black-tailed prairie dogs.

In a literature review of secondary toxicity studies of 21 mammalian, avian and reptilian predatory species, Johnson (1992) finds, *"Because zinc phosphide does not accumulate in muscle tissue of poisoned animals, no true secondary poisoning occurs...The potential for zinc phosphide exposure to scavengers from eating poisoned animals was shown in several studies conducted on rangeland. No cases of secondary exposure have been documented, primarily because scavengers avoided the GI tract of poisoned animals."*

Anitcoagulants: *"In general, anticoagulants are toxic both primarily and secondarily to both birds and mammals. Non-target rodents, rabbits, and seed-eating birds all can be killed by primary poisoning. However, gallinacious birds are quite resistant to anticoagulants. Substantial secondary hazards to raptors and mammalian predators exist with most of the older as well as the newer, more toxic anticoagulants"* (Hegdal 1987), if the predator consumes the target species' liver, which contains the greatest amount of anticoagulant residues (Record and Marsh 1988).

In a simulated worst-case scenario, Marsh and Howard (1986) –using a bait at double the label concentration–fed coyotes (no choice) one chlorophacinone-killed ground squirrel ***(S. beecheyi)*** per day for 5 consecutive days, then monitored them for 30 days. Three of the seven coyotes died, while the other four showed no observable symptoms of anticoagulant poisoning.

Matschke et al. (1986), in their testing of brodifacoum on ***G. bursarius*** state that 30 of 41 radio-equipped gophers died below ground, four slipped out of their collars (leaving their fate unknown), three were taken by predators, and four survived. However, they did find four dead nonradio-collared gophers on the surface with brodifacoum residues. Also, *"non-target mortality observed was limited to one vesper sparrow **(Pooecetes gramineus)**."* Since this study used an experimental anticoagulant applied with a burrow builder, the sparrow probably picked up poisoned bait that accidentally spilled on the surface while the machine operator removed debris from the apparatus or while raising it to turn around.



Plant roots being destroyed underground.

Askham (1988a) fed chlorophacinone-killed voles to owls and hawks, and found *"that the small amounts of compound retained by the voles at death are not sufficient to cause injury or death to the predator...The potential for secondary toxicity to two species of birds (red-tailed hawks and great horned owls) appears to be low. None of the treated birds died, nor showed signs of stress, nor prolonged bleeding. The significant reduction of active ingredient between ingestion and analysis indicated a rapid degradation and elimination of the compound in both the vole and bird systems."*

Fisher and Tim (1987) find that five of six domestic ferrets died of anticoagulant poisoning after they ate four black-tailed prairie dogs, one every other day, each poisoned with *"0.0025% a.i., a concentration lower than that in chlorophacinone baits currently registered for use against pocket gophers."* Colvin et al. (1988) state that, *"No second generation anticoagulant currently is registered in the USA for non-commensal (field) uses. Hazards to non-target wildlife probably will limit such registrations."*

NonLethal Methods of Control

Exclusion and Physical Barriers

Exclusionary barriers are expensive to install and require maintenance, but provide neither a practical nor economical method of control for plantation-sized areas. They must be built around an area with a zero population of gophers, or a 100 percent control program must occur after construction. The barrier can consist of a 2-foot (0.6-meter) deep trench, a surface wall or wire mesh below and above ground. However, gophers have the capacity to burrow beneath the barriers anyway (Noble and Alexander 1975).

"Prevention of gopher damage by a physical barrier such as caging is of questionable value" (Hooven 1971). Wire cages are expensive to purchase, install, and maintain, and gophers burrow under them anyway. When installed properly and maintained, plastic cages such as *Vexar®* tubing remain effective for only a few years. Since gophers can damage trees up to the height of the snow cover, this protection lasts only until the seedling grows to the top of the tube. If placed below ground in the planting hole, *Vexar®* can protect the seedling roots within the plastic cage. However, roots will not remain restricted within the tube, and all those that grow through the mesh can become available gopher food anyway. However, after a 6-year study, Anthony et al. (1983) find *"no dramatic differences in size or root distribution between* [Vexar®] *protected and unprotected seedlings with similar damage history."* Where baiting is not appropriate, the use of *Vexar®* tubes can cost two to three times as much to install and maintain than when not used at all (Anthony et al. 1978).

Vexar® tubes also have other disadvantages. They sometimes cause a twisting and deformation of the seedling if the buds push out the weave on the side of the tubing, or if the plastic won't break down like it is supposed to. *Vexar®* can also cause seedling damage when the tubing does not allow the seedling to bounce back after being compressed by snow.

On the positive side, Anthony and Barnes (1978) find that after two growing seasons, *Vexar®*-protected seedlings had greater stocking and height growth, and only a 5 percent mortality, versus a 20 percent mortality on unprotected seedlings.

Black et al. (1979) noted one of their plots on the Wallowa-Whitman National Forest where *"tree mortality, caused principally by gophers, reduced survival of uncaged trees to 43 percent after 5 years; 80 percent of caged trees survived. Gopher damage to both caged and uncaged trees increased in years 6 and 7. Because of poor tree survival, we discontinued observations in year 8 [of the 10-year study]."*

"Protective barriers substantially increase the cost of planting, and despite some impressive results, long-term effects on trees have not been adequately evaluated. The concept is sound, but the reduction of gopher damage with tube-type protectors presently is limited" (Marsh and Steele 1992).

Limited Use and Exotic Methods

Flooding appears impractical for most forest plantations, especially where enough water or a means to apply it are not available, or slope precludes its use. Sufficient water may drown some gophers, but when water fills the pore spaces in soil, gas diffusion becomes more difficult and makes the burrow system inhospitable and undesirable (see pages 14-18). If resident gophers can escape to the surface, they may leave a flooded area by swimming–if not pursued and killed by trained dogs–but others will return to the burrow system soon after the area dries out.

Shooting is a very time consuming, impractical, inefficient, and ineffective method because gophers so seldom venture above ground, and only expose themselves for a very short period of time.

Lantz (1903) and other early twentieth century researchers from the Midwest dismissed the use of bounties as a means of pocket gopher control. Local people brought in more gopher parts for cash than the governmental agencies could pay for, and the gopher populations apparently did not appreciably change.

Mechanically-caused ground vibrations, vented bleach bottles, or broken glass have no effect on eliminating gophers (Kuhn 1983). Neither does planting poisonous plants, such as castor bean (Marsh and Howard 1978 and Kuhn 1983). I have found no information on the efficacy of planting of *Gopher Purge®* or *Gopher Patrol®*, other than what commercial plant and seed catalogs state.

A Colorado concern has developed a "vacuum evictor" that creates *"300mph wind tunnels, literally sucking the critters out alive and depositing them in the back of the truck with hundreds of their surprised neighbors"* (Newhall 1991). The inventor calls it a *"Prairie Dog Sucker Upper,"* but since this machine mounts on a truck body, and because pocket gophers generally live one per burrow system, it has limited opportunities on forest sites.

In testing an electromagnetic device reported to control gophers and affect their reproductive behavior, Case et al. (1978) find that electromagnetic waves do not appear to affect gophers, and a captured female in their study area showed no ill effects while carrying four full-term embryos.

Repellents, Reproductive Inhibitors, and Other Chemicals

The application of predator odors has considerable potential to protect forest plantations. Odors that originate from feces, urine, or anal scent glands can elicit a "fear response" when detected by a prey species, and maybe induce behavioral or physiological stress on the target species (Sullivan, Sullivan et al. 1988). These researchers also speculate that these same odors may attract other predators, thus increasing predation of the target species.

Sullivan (1987) finds *"significant avoidance responses (behavioral modification)"* to *"synthetic constituents of weasel anal-gland secretion and red fox urine or feces"* for ***T. talpoides***. But, *"repellents suitable for protecting seedlings from gophers do not, at present, exist"* (Marsh and Steele 1992). Continuing, they state that the testing of some commercial rodent repellents showed poor efficacy in protecting conifer seedlings, and while *Thiram*® and *BGR*® have proven themselves effective against other mammalian pests, they show no promise against pocket gophers.

On the scale necessary to provide long-term protection of plantations, these methods–though politically more acceptable than poisoning–seem unlikely to protect planted seedlings from gopher damage. Barnes (1973) reports success in protecting buried cable and fruit trees from gopher damage, but Case (1983) and Marsh and Howard (1978) questioned the efficacy of repellents even if they are registered for field use. Naphthalene and paradichlorobenzene (moth balls), proved ineffective because they last only a short time. Sullivan, Crump and Sullivan (1988) state that researchers need to determine optimum concentrations and better release systems before attempting any long-term field applications. Nonetheless, once cleared of gophers, Sullivan et al. (1990) find that the post-baiting application in burrows of synthetic semiochemicals, generally clay pellets containing a synthetic mustalid anal gland compound, prevents recolonization by gophers. Areas so treated would probably remain at low population densities as long as the scent remains.

Chemosterilants cause temporary or permanent sterility in either or both sexes, or through other physiological mechanisms, reduce the number of offspring produced, or alter the fecundity of the offspring. These chemicals are very selective, and their *"manner of use presents little hazard to human beings, pets, domestic stock or non-target wildlife"* when compared with standard rodenticides (Marsh and Howard 1973). However, because *"no reproductive inhibitors or chemosterilant research has been directed specifically to pocket gophers"* (Marsh, Rex E., 1993 personal communication), and because the USDA considers reproductive inhibitors to have a low probability of success (Teipner et al. 1983), the present or future successful application of chemosterilants as repellents or reproductive inhibitors remains dubious. Although the USDA Denver Wildlife Research Center is experimenting with immunocontraception to prevent rodent reproduction, it may take many years to develop a commercial application of this method (Witmer, Gary W. 1994, person communication).

Altering the normal gene pool within a gopher population by introducing a different breeding stock, or using mutagenic compounds that induce genetic changes have also been considered (Marsh and Howard 1973). These genetic changes would attempt to make the gophers less successful in their environment, cause them to have a lower survival rate, or have some other self-destructive mechanism, such as more susceptibility to diseases or making them more prone to predation. Such genetic abnormalities have been studied in commensal rodents, but these data do not apply to the more genetically diverse gophers, and therefore, offer no prospective control in the near future.

Plant More Trees Per Acre

Although supplemental feeding programs have proven themselves successful in the management of some wildlife species, this method has not proven itself effective against pocket gophers in young forest plantations. It does, however, allow for the loss of more trees to gopher predation, and provides more winter and early spring food for hungry gophers.

Borrecco (1976) provides a correlation to this approach by providing supplemental foods to lure gophers away from tree seedlings. However, in the case of gophers living in a forested environment, I think that supplemental feeding would tend to improve the habitat, i.e., cause an increase in carrying capacity and a consequent increase in gopher survival. This in turn will necessitate the need for more supplemental feed to keep them from devouring the seedlings, which will improve the habitat further, increasing the population *ad nauseam*.

Plant Resistant Trees

Although gophers prey on all commercial western conifers (Crouch 1986), Case (1983) suggests planting provenances that demonstrate natural resistance to gopher predation. Cummins and Boyd (1975) cite a study in which northern pocket gophers *"did not preferentially select any particular source of ponderosa pine when presented with a set of seedlings from six different sources,...[but] exhibited significant preferences for seedling[s] from particular sources in terms of amounts consumed of each strain."*

Despite the fact that individual conifer seedlings show no morphological differences, their monoterpene hydrocarbon content does differ (Radwan et al. 1982). In testing for essential oils in ponderosa pine, researchers hope to find genotypes that gophers will less likely feed upon. Since some components of stem and root oils strongly correlate to gopher preference, oil constituents can serve as indicators of resistance and susceptibility to pocket gopher damage. Research along these lines may lead to the selection of genotypes that produce monoterpene hydrocarbons that pocket gophers least prefer, toward planting less vulnerable (resistant) seedlings, or to the development of repellents based on these monoterpenes.

Buffer Zones

Barnes (1974) suggests the use of at least a 500-foot (152-meter) wide buffer strip *"between logged units and gopher-populated areas."* These could consist of a no-cut area; one that had a light harvest, a brush field, or a nongopher infested grassland. Teipner et al. (1983), however, caution that gophers travel along roads and through partially cut areas with little overhead shade removed, and cite a case where an individual northern pocket gopher traveled 2,590 feet (797 meters) on the surface.

Buffer zones essentially reduce the potential damage to seedlings by extending the distance pocket gophers have to travel to move into the harvested area. Although they only provide a temporary respite, they become more effective when used in combination with other measures of direct control, such as toxic baiting. Conducting gopher control in these adjacent areas will also slow down the immigration into the cutover area.

Habitat Manipulation

Proactive preventive management can obviate the need for, or intensity of, intensive post-harvest gopher population control. *"In the future, indirect or ecological control involving habitat modification may prove to be a more effective and less costly management approach. This method usually entails changes to make the target area less suitable for gopher occupation"* (Forest Service Handbook 1988). Although many conifer plantations can support endemic populations of pocket gophers with no apparent "damage" (Crouch 1982), habitat manipulation can reduce gopher damage and potential population levels. Properly planned and applied silvicultural practices can minimize habitat conditions favorable to gophers, thus providing the most practical solutions for preventing damage and allowing for the greatest potential for effective, long-lasting control.

Locating a gopher plot.

"The plant succession predicted for a site after logging, its capacity to support a high population of gophers, and the current abundance and distribution of gophers on the site and adjacent lands, are the major factors predisposing a new plantation to significant gopher problems" (Marsh and Steele 1992). Forest

management practices alter vegetation, which in turn affects the habitats for the endemic populations of wildlife. Land managers need to know the feeding habits of pocket gophers in their local forested habitats, i.e., the preferred forage species and the relative volume consumed, and the feeding habits of the local gopher predators (see page 29). This information allows land managers to predict–and assess with some accuracy–how vegetative changes will affect gopher populations.

Even though pocket gophers can adapt to a wide range of environmental conditions, *"in many instances, gopher damage could be avoided or reduced through early recognition of the animal's probable response to habitat changes that result from silvicultural treatments"* (Forest Service Handbook 1988). Closely associated with where one establishes silvicultural treatment boundaries, are the topographic and physical characteristics that influence pocket gopher habitat suitability. For example, rock outcroppings and streams generally restrict gopher movements (except through snow), and slopes greater than 35 percent generally support lower populations of pocket gophers (Marsh and Steele 1992).

Mechanical site preparation, which probably matches clear-cutting as the most favorable method to improve gopher habitat, especially on shrub-dominated sites, leaves the forest floor with mounds of loose soil, especially in long, uninterrupted strips. Such soil conditions encourage invasion by gophers, not only making it easier for them to dig burrows, but it leaves the ground more receptive to the germination and growth of the seral plants preferred by gophers.

Graham and Kingery (1990) find that in heavily disturbed sites (machine yarding and machine piling of logging debris, plus grass seeding), pocket gophers caused up to 71 percent mortality of the planted trees, with cattle grazing causing less than 4 percent. In contrast, their *"moderate site treatment did not create conditions that favored large pocket gopher populations, and gopher damage and mortality were within acceptable limits."* They concluded that grazing reduced competing vegetation in plantations, but *"did not appear useful in reducing pocket gopher populations through habitat modification."*

Many researchers have quantified the obvious, i.e., more herbage (suitable food for gophers) grows under an open canopy than under a closed one. Hence, leaving advanced reproduction and other understory vegetation, or keeping the harvested area covered with deep slash, minimizes soil disturbance, shades the ground, and reduces the probability that gophers will invade the area. Also, as the shrub component increases, gopher populations tend to decrease for lack of suitable forage. Marsh and Steele (1992) suggest that sowing vegetation in newly harvested areas that can compete with gopher-preferred foods may have merit in some circumstances. For example, sowing fine-rooted grasses helps prevent the invasion of bull thistle, an important food plant for gophers east of the Cascades, but sowing brome, orchard grass or timothy would help support gophers.

Marsh and Steele (1992) also cite a study in some grand fir and Douglas-fir habitats wherein clearcuts scarified without burning had gopher activity, but similarly scarified and broadcast burned sites, or just broadcast burned areas had *"virtually no [gopher] activity."* Mechanical scarification encourages the growth of early seral species favored by pocket gophers, whereas burning created dense shrub layers and mid-to-late seral herbaceous layers not favored by gophers. They also cite examples where similar areas burned by wildfire did regenerate to habitats favored by pocket gophers, stating that *"wildfire and prescribed burns, unless extremely hot and very slow moving, have almost no direct, detrimental effects on gophers, because these burrowing rodents often have nests more than 4 feet belowground."*

Since some timber types do not lend themselves to partial cutting silvicultural systems, planting within 1 year of harvest, which allows the tree seedlings to establish themselves before the herbaceous vegetation increases enough to support a large population of gophers, and planting large seedlings, which better withstand gopher damage, may sometimes maintain gopher predation to acceptable levels. Practices such as protecting thrifty advance regeneration during logging not only supplement post-logging planting, but reduce the amount of disturbed areas that favor gopher intrusion.

Therefore, prompt and successful regeneration after timber harvest, wildfire, or insect damage minimizes the opportunities for colonization by gophers. Ideally, tree growth should outpace the damage caused by gophers before the regenerated area develops into prime gopher habitat. But if gophers do gain a significant foothold, land managers may need to treat the area periodically until the trees essentially compete with and grow despite the damage caused by gophers.

Eliminate Food Supply

The abundance and distribution of wildlife, even nonconsumptive wildlife such as pocket gophers, is a function of its habitat, i.e., food, water, and cover. These three items form the essentials, whose availability or quality must change to reduce or prevent wildlife damage (Borrecco 1976). Forest management practices such as prescribed burning, timber harvesting, herbicide treatments, scarification and intensive livestock grazing alter the physical availability of these factors. Since gophers receive sufficient water from their food items, they can subsist without free water (Scheffer 1910). Therefore, herbage composition and total vegetative production constitute very important factors in predicting gopher response in a specific area.

Since forage production is a very critical factor determining pocket gopher population levels, any management practice that stimulates the production of succulent forbs will improve the habitat for pocket gophers. The reverse is also true. If you reduce the availability of succulent forbs, the endemic population will revert to eating marginal and other less preferred foods, thereby reducing their ability to survive, multiply, and adversely affect forest plantations.

Although poisoning produces good results, the most promising –though controversial–method to control gophers is to apply a herbicide to eliminate plants preferred by gophers. Herbicides modify the local habitat enough to make it unsuitable for gophers by eliminating the vegetation that the gophers feed upon, and by improving growth on the conifer seedlings that remain on the site by making more moisture and nutrients available for their growth and development. *"Pocket gopher activity declined in response to vegetative management, but lagged about 1 year after application of herbicides. The greatest reduction in gopher activity occurred on areas with complete control of vegetation"* (Black and Hooven 1977).

A fall treatment of atrazine *"doubled survival of planted pines and greatly increased their height growth"* (Crouch 1979). His treatment not only reduced the population of grasses and forbs significantly–though shrub growth increased–it also controlled competing plants for the next nine growing seasons! However, his spring treatment failed because not enough precipitation fell to translocate the atrazine to the root zone after the chemical application.

Black and Hooven (1977) find that vegetative management–eliminating the gophers' food supply and cover–has the potential to accomplish effective, long-term control, and Hooven and Black (1978) find that the gopher population took a major decline after they sprayed a xeric ponderosa pine stand with atrazine, simazine and 2,4-D. Their use of these three herbicides created a more favorable environment for seedling survival, and caused a marked reduction in gopher activity 1 year after spraying. *"On areas treated with atrazine, simazine and 2,4-D, gopher activity was only about one-tenth of that observed on untreated areas"* (Black and Hooven 1977).

Keith et al. (1959) report that treatment with 2,4-D reduced the gopher-preferred foods by 85 to 100 percent, and the gopher population decreased. *"Extensive feeding trials revealed that direct ingestion of 2,4-D sprayed on grasses and forbs resulted in no apparent toxic effects to gophers"* (Teipner et al. 1983).

Habitat manipulation through the use of herbicides creates an environment less suitable for gophers, and since the amount of palatable and preferred vegetation available heavily influences population density, altering that vegetation has the greatest potential to achieve effective, long-lasting control. Also, accomplishing this 1 year before planting allows the gopher population to decline for lack of food, thus increasing the probability of seedling survival. If planting takes place immediately after the herbicide treatment, the planted conifers provide the only available source of food, and the gophers will eat them.

Sullivan and Hogue (1987) find that the population of gophers and the amount of gopher damage decreased in the herbicide-treated areas of an orchard compared to the nontreated portions. The former, because of the lack of suitable forage, provide poor choices for recolonization by gophers from outside the treated area, and poor places for the young-of-the-year to remain. Also, because of the lack of vegetation, any small rodent exposed on the surface becomes easier prey for natural predators.

Integrated Pest Management

I recommend this method because it provides an integrated approach, which brings together a sound ecological knowledge base about gopher damage prevention, and the recent technological advances in control measures that consider the full range of alternative means of forest protection. Some land managers now emphasize this more integrated, holistic management method to animal damage control by first defining the resource management objectives and constraints prior to prescribing any preharvest manipulation, followed by chemical control and biological repellents if needed.

Planned programs such as these will prove more effective because they integrate the population dynamics of gophers with land management options, and a sound understanding of the ecological consequences of management decisions based on ecosystem-oriented analyses. Walstad and Norris (1992) sum up this method by stating that despite the efficacy of direct and indirect animal damage control methods, *"they have not completely satisfied the concerns of either the public or forest resource managers, [who need] better integration of such practices within the overall context of silviculture and forest protection, rather than continued dependency on reactive, 'quick fix' solutions to animal damage problems."*

Put in an ecosystem management perspective, land managers use a more mature ecological approach to blend society's needs for wood–with the requirements naturally established by the environment–to maintain a healthy, productive, biologically sustainable ecosystem, stressing preventative measures over corrective ones. In other words, instead of trying to manage a plantation for maximum growth, land managers pay more attention to the true ecological processes, which determine the capability of the ecosystem to sustain tree growth, consumptive wildlife, and nonconsumptive wildlife, such as pocket gophers.

Because they feed opportunistically, pocket gophers can adapt to different vegetative communities within the ecosystem. Therefore, land managers not only maintain a healthy, growing plantation, but also maintain on a larger spatial and temporal scale, a more functional ecosystem, including endemic populations of consumptive and nonconsumptive wildlife. So in the long run, land managers can probably discount the small amount of damage that an endemic gopher population causes.

Gopher activity and seedling survival have a linear relationship to the reduction in vegetative cover, especially perennial grasses. Black and Hooven (1977) find that *"as the cover declined, the environment became less favorable for gophers and more favorable for tree survival; occurrence of gopher damage and losses to drought (caused by moisture stress) were reduced and seedling survival improved."*

"Many instances of gopher damage could be avoided or modified through early recognition of the animals' probable response to habitat changes and by prompt application of direct or indirect control measures" (Barnes 1974). Although protecting an already existing plantation constitutes an acceptable practice, *"protecting conifers is difficult on a plantation densely populated with gophers. Recruitment of animals from inside or outside the plantation boundaries will tend to maintain the habitat at or near its carrying capacity"* (Barnes 1974). Rather than confronting a gopher problem under these conditions, an integrated preventative management approach, i.e., anticipating potential damage and precluding a population buildup that would cause the damage, offers a superior approach.

The identification of plant communities can also aid in classifying areas possibly susceptible to gopher infestations. Land managers need to field identify and map out such plant communities and habitats that contain, or can be invaded by, highly preferred plant species, and plan to have minimal ground disturbance to these areas. Although the literature contains little to no information on gopher prediction models and risk assessment formats, Horton (1987) offered a preliminary pocket gopher prediction model developed for southcentral Oregon. He qualified it with statements that some failures tested the limits of his model, and required on-going refinements to separate high risk from moderate risk areas. In any case, such information merely indicates, not proves, that a gopher invasion might occur. Also, *"natural or near-natural buffers of undisturbed strips of 400 to 600 feet in width between gopher-occupied areas and sites selected for harvest provide protection against rapid invasion by gophers"* (Marsh and Steele 1992).

No standard relationship exists between the environmental factors that govern tree growth and those that govern the preference for gopher habitation. However, as indicators of their environment, plant communities can correlate with potential gopher damage because plant communities differ both in herbaceous composition and production. Stratifying these plant communities based on the risk of gopher occupancy allows land managers to allocate control resources to the sites of greatest risks and those of greatest value (Volland 1977).

Barnes (1974) stresses the importance of pretreatment reconnaissance to assess the gopher situation, and to make a determination of: which harvest treatment to use; whether buffer strips apply; whether the harvest area or the adjacent gopher-occupied areas need pretreatment; or whether post-planting gopher control measures seem appropriate. DeCalesta and Asman (1987) state, *"You'll achieve maximum effectiveness of most control techniques if you can employ them* ***before*** *[sic] you plant seedlings. Most forest managers are willing to apply control techniques before planting only if there is high likelihood of damage."*

Using a loop to locate radio-collared gophers.

Using a "yaggie" to locate radio-collared gophers.

The increasing emphasis in the 1990's on improving our silvicultural and vegetation management practices will probably allow land managers to prevent or limit animal damage in the future. However, attempting to alleviate gopher damage solely by manipulating vegetation, i.e., to affect the gophers' food and cover adversely such that the gopher population declines in the treated area, may create dilemmas. Land managers can identify and rate areas of potential damage, and consider other regeneration practices besides clearcuts. Prescription writers can include special marking guidelines and sale administration suggestions that will result in more standing trees, more undisturbed vegetation and less soil movement–all of which will slow down an invasion of gophers from adjacent areas–if such practices will not interfere with the chosen land management option. In order to determine which combination of solutions best fits the on-the-ground situation, foresters must work closely with wildlife biologists and other natural resource specialists to produce the plan that best meets the land management objectives with the least unwanted side effects. In other words, the collective wisdom of many outweighs the possible folly of one.

Also, given the present political climate that does not portend a favorable future for a heavy reliance on the field application of poisons, any planned control measures must harmonize with, not conflict with, other prescribed silvicultural practices for the harvested area. Also, since the early years of animal damage control, land managers have finally *"developed a better appreciation for the ability of seedlings, trees, and stands to recover from damage; what was once thought to be severe damage has sometimes turned out to be inconsequential by the second or third decade of stand development"* (Walstad and Norris 1992).

Concerning "New Forestry," Black (1992) states that it *"involves new approaches to forest regeneration and stand and landscape management, including practices that increase habitat suitability for problem species and other wildlife,...[and] will have a major impact on ADM [animal damage management] in the future...Pocket gopher populations and damage, for example, may increase in shelterwood stands and other stands harvested with New Forestry practices,...New Forestry is likely to improve habitat conditions and potential for increased damage by most of the wildlife species that cause damage to forest stands...."*

To evaluate its effectiveness, animal damage control, like any other active management tool, needs an established monitoring system in place. Not only will monitoring demonstrate whether the management tool succeeded in controlling gopher damage, but whether the land managers have met the Forest Plan assumptions, protection goals, standards and guidelines. The Rogue River National Forest for example, (Alexander 1991) has established a six-point Gopher Baiting Program Monitoring Plan. Besides stressing effective contract administration, it also requires searching for, and autopsy of, any aboveground carcasses found on the treated areas, a provision to maintain records, and an annual consultation process with APHIS on their contracting and monitoring activities. Districts on the Wallowa-Whitman National Forest can initiate similar monitoring programs.

Pocket gopher with a radio collar.

Economics

Land managers must dispense available financial resources efficiently. They cannot feign indifference to the relationship between the costs of animal damage control and what such attempts at control accomplish, because they may find themselves on the unfortunate high end of the curve of diminishing returns, that is, the costs of control exceeding the benefits of control.

Computing an economic analysis for pocket gopher control and damage seems complicated because we lack sufficiently detailed surveys and damage data, especially underground effects. Since costs increase over time, and some plantations need treatment for up to 10 years, we need to compare control costs to the values of the protected plantations, and to the values that the same expenditure of funds could produce someplace else. If reforestation efforts increase to meet expanding demands for wood products, gopher depredation (damage, loss of growth, extended rotation age) and the concomitant economic inputs (control costs) will also increase.

A benefit/cost ratio appears quite simple. Recent experience can provide us with an approximate cost of control. The savings that result from spending those dollars becomes uncertain because the land manager must predict how much damage would occur if no gopher control takes place, and how much damage the control would suppress.

Attaching dollar values to all the possible benefits and costs for gopher control introduces many complications. Although possible to determine the value of a complete loss, an economic analysis which compares the cost of control to the economic cost of no control, i.e., the expected damage and loss of growth, becomes problematic because of the very difficulty of determining the cost of no control, and defining the not readily recognized long-term benefits of having gophers on site as compared with the obviously substantial short-term damages.

Teeguarden (1969), in his paper on the economics of reforestation in relation to wildlife, concludes that *"because an estimate of damage reduction is based on estimates of plantation value and is essentially a speculative figure, the analyst cannot say with certainty that a given practice is or is not economically sound."*

In their economic evaluations of coniferous plantations in Oregon and Washington, Brodie, et al. (1979) suggests that *"5 years proved a sufficiently long period for evaluating the impacts of early animal damage."* Notwithstanding all cost and benefit assumptions, the economic model proposed by deCalesta (1985) demonstrates that applying control measures *"before damage occurs is more cost-effective than withholding application until it is established that damage will occur."* Therefore, if land managers have a fixed amount of dollars to spend on tactical animal control, they need only consider the most effective use of those funds to reduce potential damage without undue harm to the ecosystem itself.

Black (1992) in discussing the possible impacts of "New Forestry" to the economics of animal damage control, states, *"New objectives of resource management with greater emphasis on noncommodity resources, however, may reduce the economic costs assigned to animal damage because of reduced or delayed timber yields (especially on public lands). We do not know, however, how these impacts will change or how their significance will be assessed in the future."*

Conclusion

Because the problem with different species of pocket gophers extends from the Midwest and Southeast to throughout the West, it is unlikely that the development of one single technique or bait will apply in all situations. Continued interest and increased support for applied research can promote development of alternatives, and give land managers more information on organizing effective control programs. Research needs include: how silvicultural prescriptions and pocket gopher densities and damage correlate; baiting techniques; improved baits; and since the use of herbicides has shown itself efficacious in some forest communities, a means to identify which plant communities can best adapt to this method.

In as much as damage prediction over time becomes more and more imprecise each year into the future, and since weather, site conditions, tree growth and gopher populations will continue to vary widely, the key to minimizing the impact of the northern pocket gophers means monitoring the affected areas often enough to treat the areas if damage reaches the limit established by the land manager. Since known needs and values vary for different components of the environment, pocket gopher control must sometimes be looked upon as an end in itself.

Therefore, I recommmend the implementation of the integrated pest management strategy for pocket gopher control on the Wallowa-Whitman National Forest. Our skillful, integrated use of the ecological knowledge of pocket gopher behavior must apply not just to controlling the pocket gopher populations in selected units, but we must also bear in mind that pocket gophers serve as an important and essential component of the diverse ecosystems on the Forest, and affect the total production of both consumptive and nonconsumptive forest products and resources.

The silviculturalist must determine the gopher susceptibility of a stand during the prescription stage, and use all logical methods mentioned earlier to discourage the immigration of pocket gophers into the timber-harvested areas. If these prescribed methods still do not prevent the invasion of pocket gophers, and sufficient gopher damage results, I recommend that District Rangers thoroughly analyze the site-specific conditions of each proposed gopher control area using the NEPA process. If, after analysis, they determine that plantation values warrant control, I recommend the application of herbicides for vegetative management, if and where appropriate, to abate the gopher-preferred foods, and as a last resort, the application of 0.5 percent strychnine-treated oats at the label-recommended rate to the gopher-infested areas and to a 500-foot buffer zone around them.

The need for timber products reflects our social, economic and political climate–as communicated to the USDA Forest Service by the American people through their Congressional representatives. The specific purpose of gopher control allows land managers to produce, restore or sustain certain ecological conditions conducive to the production of timber resources in widely scattered harvested units. The short-term pocket gopher population changes produced by approved control methods, with specific management objectives in mind, will not affect the long-term diversity or resiliency of the Forest, but will definitely increase the productivity of trees in the areas carefully selected for gopher control.

The integrated scientific knowledge expressed in this paper explains the relationships involved between pocket gophers and the environment. A more global overview must replace the examination and consideration of only single units upon which we want to control gophers. We must examine the impact of gopher control on these scattered and selected units from the standpoint of total productivity and sustainability of all forest resources from the present until forever. Therefore, by applying ecosystem management principles–rather than pure resource management principles–we must consider and take into account more ecological elements and arrive at a balanced solution that harmonizes ecologically with our total forest ecosystem.

Since the future will bring in new knowledge concerning animal damage control, we as land managers, must practice a form of adaptive management. We will have to determine whether our selected gopher control process has met the predetermined objective of reducing the danger to planted seedlings, thereby achieving the desired economic objective of a sufficient number of live, healthy, seedlings to regenerate the units within the landscape-based ecosystem.

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